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Conservation
Service

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Installer/Inspector Qualifications Workbook

Renewable Resources

SERI/SP-722-1130
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Solar Energy Research Institute

Operated for the
U.S. Department of Energy
by Midwest Research Institute

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INTRODUCTION

The original intent of this workbook was to draw together all the diverse areas of knowledge required to be qualified as an installer or inspector of renewable resource measures under the Residential Conservation Service (RCS) Program. It can now be said that the accomplishment of this task, in a comprehensive manner, was impossible given the restraints of budget, staff, and schedule. What has been produced, though, is a compendium of information which, when used within its limitations, should be a helpful resource to prospective installers and inspectors of renewable measures.

One limitation of this workbook is that its content and depth of discussion of each topic is restricted to the general guidelines of the RCS rule (reproduced as it relates to renewables in Appendix A.1). Therefore, in an effort to avoid further delays and volumes of information, each topic within this workbook has been carefully edited to ensure that Section 456.314 of the regulation has been sufficiently addressed with state-of-the-art knowledge. As a result, several topics may seem out of place in a renewable resource document, but are included here because of their indirect relationship with a renewable resource measure. For example, Chapter 5, "Conventional Heating Systems," provides information about the design, operation, installation, and maintenance of various types of domestic water and space heating systems commonly found in U.S. homes today. However, the information on these types of systems is limited in scope to the guidelines of the RCS rule which primarily addresses the interconnection of these systems with a solar energy measure.

Other sections, while not explicitly called for in the regulation, have been included as background information that should help an installer or inspector tie together the various chapters. For example, Chapter 2, "Active Solar Systems", not only provides information about active solar systems that can be helpful in a review or "primer" capacity, but also leads into critical areas such as the interconnection mentioned above, and other topics discussed in later chapters.

With the exception of Chapter 6, "Passive Solar Systems," the remainder of the chapters cover topics that the RCS rule requires installers and inspectors to know in order to qualify under the RCS Program. Chapter 6 is not completed at this time primarily because inspections of passive solar measures are not required by the RCS regulation and because of a general lack of standards related to passive solar installations. However, the important role of passive systems should not be overlooked, and research on installation and inspection techniques is now being conducted for future inclusion in this workbook.

While somewhat limited, there are standards presently in place that address active solar systems. The RCS has adopted the Department of Housing and Urban Development's Intermediate Minimum Property Standards (HUD/IMPS) as minimum standards relating to active solar systems. These standards are referred to throughout this workbook, and space has been provided for their insertion, in their entirety, as Chapters 8 and 9.* These documents can be ordered from the U.S. Government Printing Office and ordering information is included in the appropriate chapters of this workbook. All recipients of this workbook are encouraged to purchase and insert these two documents into their workbook not only because the material covered in this workbook is based on HUD/IMPS, but also because the HUD/IMPS document is part of a subscription service, and all forthcoming supplements will automatically be forwarded to the recipient. Therefore, any changes or additions to the standards that govern RCS active solar installations will be brought automatically to the attention of those it may affect the most.

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*Participants in the RCS Installer/Inspector Seminars were provided these documents as additional materials included in their registration fee.

In April and May 1981, DOE, SERI and their contractors conducted a series of RCS Installer/Inspector Seminars in five different cities across the U.S. Those seminars were one and a half day sessions in which the participants (mainly RCS program managers or RCS training coordinators from utiltiies) were given orientation lectures about the DOE/RCS technical assistance materials. The materials were specifically prepared to assist in the installation and inspection of RCS energy conservation and renewable resource measures. This workbook is one such document and encompasses all topics related to renewable resource measures that were discussed during the seminars. If used in conjunction with the RCS Inspector's Guide, this document should serve your needs and help in the attainment of a larger goal: quality installations of energy-conserving devices.

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CHAPTER 2

ACTIVE SOLAR SYSTEMS

2.1 INTRODUCTION

Solar heating is receiving widespread attention today, meeting many residential heating needs as a practical alternative to conventional fuels. This fact is somewhat ironic since solar heating is by no means a new phenomenon. Instead, the current interest in solar is a revitalization of a technology widely-used for thousands of years. Some 2300 years ago, Socrates wrote that citizens should carefully orient their buildings towards the winter sun and utilize certain building materials and colors to provide natural heating and cooling. The same concept can be traced in the New World, when in 700 A.D. American Indians were displaying exquisite solar architecture in such cliff dwellings as Montezuma's Castle in the Verde Valley of Arizona. Winter heating was provided by calculated solar warming of exposed thermal mass. Summer cooling was maximized by huge overhangs blocking the high sun and by cool breezes from the valley to the south.

In the nineteenth century, work and research on solar energy continued. For example, the famous American inventor John Ericsson, designer of the ironclad warship the Monitor, designed and constructed seven solar steam generators. In the late 1800s, solar water heating became common-place in this country, largely as a result of the oppressive heat created by wood fires used in summer for water heating. By 1900, 30% of all homes in Los Angeles were outfitted with solar water heaters. By 1930, 50% of the homes in Miami had solar systems.

Because of cheap fuel prices during the 1930s and 40s and due to copper shortages during World War II, the solar industry dropped behind. Solar interest was confined to research work at a handful of academic centers such as the Massachusetts Institute of Technology. In 1973, however, the oil embargo signaled renewed concentration on the potential of solar heating, and enthusiasm has continued to grow. It is noteworthy that solar installations are now doubling in number each year in many parts of this country. Equally significant, is the fact that solar application is far advanced in other countries where conventional fuels have not been price-controlled. For example, at present there are more than 3,000,000 solar water heaters in operation in Japan, a country equivalent in size to the state of Montana.

As solar heating has become an increasingly important factor in this country's energy mix, certain conceptual distinctions have been made to help categorize the many different types of solar applications. The basic differentiation is between passive and active systems.

A passive system is one which uses no external energy to move the collected solar heat. A good example would be the Arizona cliff dwellings which rely simply on the sun warming the thermal mass of the stone walls. Passive designers are fond of referring to the earth, spinning daily in its annual orbit around the sun, as the only moving part in a passive system.

An active system, on the other hand, does use mechanical energy to move the solar-derived heat. The power may be used in a circulator, a pump, or a blower. An example of an active system is the thirty-two collector solar water heating system on the White House which uses a 1/4-horse power pump to take the solar heat down to the West Wing mechanical room when there is energy to be collected.

2.2 BASIC COMPONENTS

2.2.1 Collectors

The basic unit of active solar technology is the solar collector, a device which captures radiant energy from the sun and converts that energy into useful heat. There are many different types of solar collectors, as evidenced by the hundreds of companies in the United States now engaged in their manufacture. The most common types of collectors are concentrating, evacuated tube, and flat plate. These types vary dramatically in their design and their costs. Perhaps even more importantly, however, they vary in the temperatures which they can achieve, as Figure 2-1 illustrates.

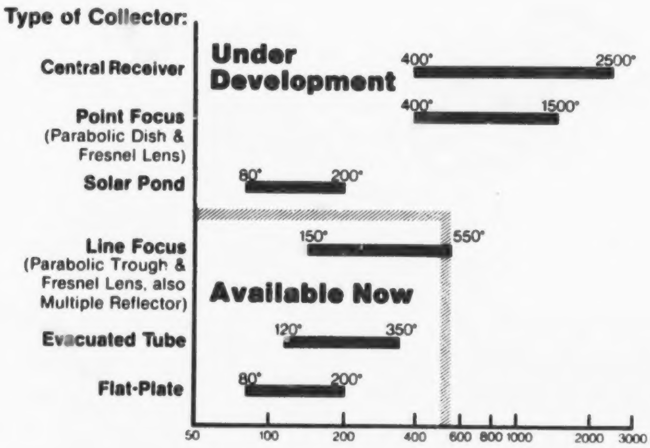


Figure 2-1. Temperature of Collectors

The operating temperatures of collectors are critical to the type of application. It is inefficient to use a sophisticated high-temperature collector when only low-grade heat is needed as with house heating. Similarly, a low-temperature collector would not be appropriate when high temperatures are required, as with steam generation.

All collectors, however, share an important consideration beyond cost and efficiency. Any collector must be able to withstand enormous weather and temperature extremes over time. Durability is of great concern because solar systems tend to cost more at the outset than other types of heating systems.

Concentrating Collectors

Concentrating collectors concentrate radiant energy optically before transforming it into heat. Radiant energy hitting a large aperture is concentrated, or focused, by reflection or refraction onto a small absorber area called the target or receiver. A famous early example of a solar concentration scheme reportedly took place in 212 B.C. Archimedes instructed the Grecian army to stand on a shoreline hillside and direct their shields toward a Roman fleet on its way to Syracuse. The sun's light, bouncing off the many highly reflective shield surfces, was focused so intensely on the ships' sails that they caught fire.

It is interesting to consider that the reason that concentrators can develop such high temperatures is not because any energy is actually gained. Instead, heat and efficiency are increased because the absorber area is relatively small and thermal losses are thereby reduced.

Most concentrating collectors depend on mechanical systems to enable them to track the sun because they utilize only direct, or parallel-beam, radiation. This type of pure sunlight comes from a clear sky. Concentrators are not effective at collecting heat from diffuse, or scattered light, the type of radiation evident when conditions are cloudy, hazy or foggy. For this reason, concentrators tend to be more useful in areas where the incidence of sunshine is most direct. On the average, about 50% of solar radiation is lost in the earth's outer atmosphere and in clouds. In this country the radiation lost varies between 30% in Albuquerque to 60% in Seattle.

Two typical concentrating collectors are illustrated in Figs.2-2 and 2-3. Although such concentrating collectors can operate at fairly high temperatures (over 500°) and can operate quite efficiently (up to 70%), high cost and technical complexity have made them largely inappropriate for residential usage. It is likely that their most frequent applications will be for process heat needs in the industrial sector such as is necessary for laundries, pasteurization, and food dehydration.

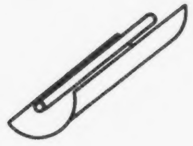


Figure 2-2. Two-Dimensional Reflecting Linear Concentrator

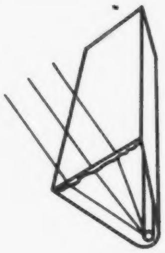


Figure 2-3. Two-Dimensional Refracting Linear Concentrator (Fresnel Lens)

Evacuated-Tube Collectors

Another type of high temperature solar thermal collector is the evacuated-tube (see Fig. 2-4). The concentrating collector achieves high temperatures by focusing light on a small area; the evacuated-tube collector achieves high heat by utilizing a vacuum tube to contain the absorber. The vacuum significantly reduces convective heat losses, allowing high performance. Generally, several evacuated tubes are connected in parallel to a manifold, giving a balanced flow network as in any collector. Liquid or gas may serve as the medium to carry the absorbed heat to storage.

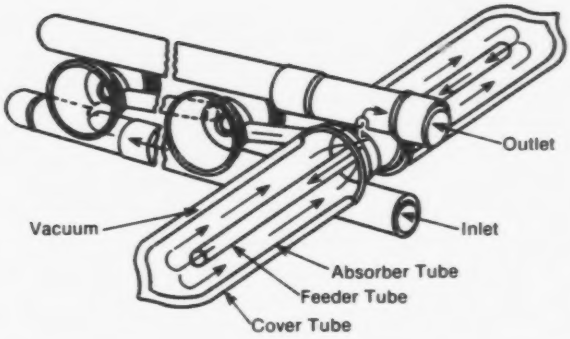


Figure 2-4. Evacuated Tube Solar Collector

Evacuated-tube collectors may some day be mass-produced in a manner similar to the manufacture of fluorescent light bulbs. However, at the present time, the relatively high cost of these collectors makes them too expensive for residential space or water heating. Since evacuated tube collectors can achieve consistent operating temperatures in the 300°F range, it is possible that they will play a greater role in the future in solar air conditioning where high temperatures are necessary.

Evacuated tubes have an inherent advantage over concentrators in that they can collect heat from both direct and diffuse light. This feature is particularly important in areas of the country such as the Midwest and Northeast where cloudy weather is common.

Flat-Plate Collectors

By far the most widely-used type of solar collector today is the flat-plate. The large black collection area is oriented in a fixed position toward the sun. The light energy striking this absorber is converted directly to heat energy. A heat transfer medium (water, antifreeze, gas, or air) is passed by the absorber and carries the collected heat away for direct use or to a storage unit for later use. Compared with concentrating or evacuated tube collectors, flat-plates are quite simple. No complex geometric or evacuated construction is required; generally, no devices to track the sun are used.

The temperatures achievable from flat-plate collectors (80° - 200°F) are considerably lower than those from concentrators or evacuated tubes. However, these lower temperatures are well-suited to many heating needs in the residential sector: domestic water heating, pool heating, and often, space heating. In addition, costs of manufacture and installation of flat-plates are comparatively low. It is probable, therefore, that the vast majority of solar systems installed under residential programs such as RCS will feature flat-plate collectors.

Unglazed Flat-plate Collectors. The most basic form of flat-plate collector is the unglazed panel which has become popular for heating outside swimming pools. It has been estimated that close to 100,000 unglazed solar swimming pool systems are now in existence.

An unglazed flat-plate collector relies simply on a black absorber surface, usually consisting of dark coated copper or a high temperature black thermoplastic such as polypropylene as shown in Fig. 2-5. Circulation of large amounts of water through many small channels (risers) in the absorber remove the solar-derived heat, keeping the absorber cool and receptive to further solar collection. This type of collector is usually large, typically 4 x 10 ft (40 ft^2).

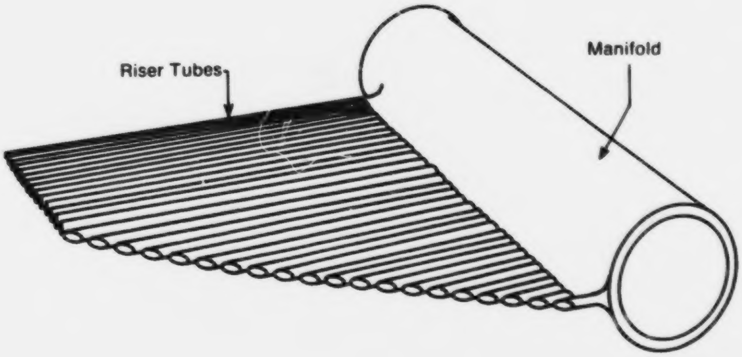


Figure 2-5. Cut-away Section of Typical Polypropylene Pool Collector

Unglazed collectors are efficient only when ambient (outside) temperatures are warm, such as when people usually wish to swim in an outdoor pool. The low temperature differential between the air and the collector absorbing surface is conducive to very efficient collection. Neither insulation nor cover glazing is required, and often between 75% to 90% of the average solar radiation can be transformed into heat energy. In good conditions, operating temperatures of 100° are common in such pool collector systems.

Unglazed collectors are not suited for use in cold weather. In fact, when ambient temperatures are 15° or more below the collector temperature, losses become so great that no meaningful heat can be generated.

Although the technology of unglazed collectors seems straightforward and they are by far the least expensive active systems available, unglazed collectors still face many of the problems encountered by more sophisticated collectors. In the case of unglazed collectors, the most important characterics are resistance to ultraviolet light and to thermal expansion and contraction.

It is absolutely necessary for unglazed collector surfaces to have a high degree of ultravoilet stability. Approximately 5% of the sun's radiation is received on earth in the ultraviolet band. Many materials (metals, glass, etc.) are essentially unaffected by ultraviolet light, but other materials may be damaged irrevocably. A familiar example of ultraviolet degradation is the bleaching, fogging and embrittlement of the plastic rear window in an automobile with a convertible top. Under the same conditions, the front glass windshield remains clear and strong. An absorber plate with insufficient ultraviolet resistance can crack, soften, or undergo other changes that would result in premature failure. Unglazed panel manufacturers using absorber materials other than copper, which is essentially impervious to ultraviolet light, must select their materials very carefully.

Additionally, unglazed flat-plate collectors must be carefully constructed and installed to allow for many cycles of thermal expansion and contraction during their lifetime. Facing south, often on windy roofs, solar collectors are continuously exposed to the most rigorous weather conditions. They often must withstand alternating freezing temperatures in winter and scorching heat in summer. Almost all materials expand and contract somewhat with thermal cycling, and in the case of solar collectors, thermal stresses can cause checking, cracking, blistering and other damage which can impair performance as well as create a safety problem. For example, several years ago a number of manufacturers of thermoplastic swimming pool collectors experienced problems with the "welds" (the interface of the riser tubes and the manifolds) that cracked from thermal cycling, resulting in collector fluid leakage.

Much manufacturing and field experience in unglazed collectors has benefitted the solar industry already. It is natural that applications such as pool heating have received early attention in the solar movement since the strong summertime sun can be used. The technology has developed to the point that many manufacturers of unglazed collectors now offer ten-year warranties on their products.

Glazed Flat-Plate Collectors. Glazed flat-plate collectors (Fig. 2-6) rely on the same thermodynamic principles as the unglazed version. However, the addition of a glazing (or cover glass) and an insulated casing can dramatically increase the temperature output of the collector. These modifications also can make the production of heat possible when ambient temperatures are low, as in winter. With glazed flat-plate collectors, common outlet temperatures of 160° make year-round heating of domestic water very attractive and space heating of homes during cold months often becomes feasible.

There are four generic components common to all covered flat-plate collectors: the glazing, the absorber, the insulation and the case.

Glazings. A glazing, or cover plate, can minimize reradiation and convective losses from an absorber much the same way that a storm window allows visible (and infrared) light into a home, but reduces heat losses from the interior. A collector glazing diminishes convection because of the resistance created by the air space between the absorber surface and the glazing. Additionally, radiation losses are reduced because glass is almost transparent to shortwave (solar) radiation but nearly opaque to long-wave (thermal) radiation. This phenomenon, achieved by placing glass over an absorber, is called the "greenhouse effect".

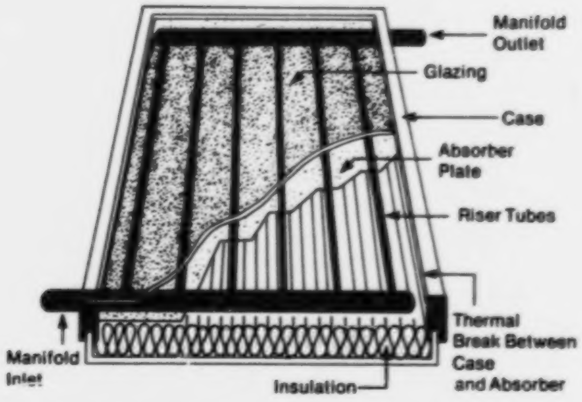

Manifold Outlet
Glazing
Case
Absorber Plate
Riser Tubes
Thermal Break Between Case and Absorber
Insulation
Manifold Inlet

Figure 2-6. Typical Glazed Flat Plate Collector

Figure 2-7 demonstrates the gains and losses of a flat-plate collector. On a favorable solar day, an efficient collector can capture 65% of the radiant energy which strikes it.

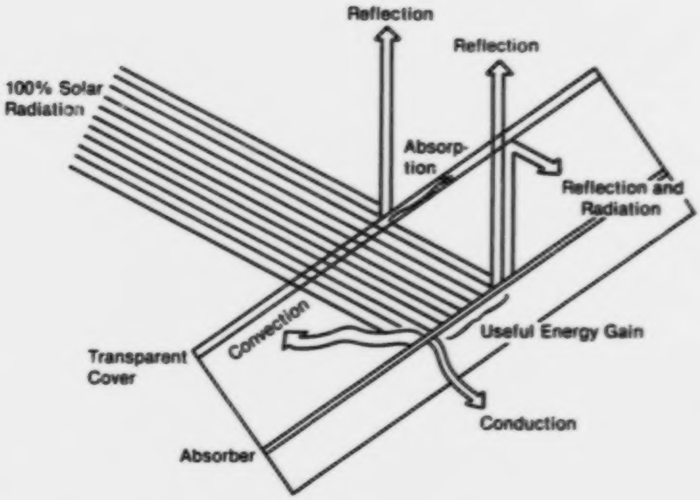

Reflection
Reflection
100% Solar Radiation
Absorp-tion
Reflection and Radiation
Convection
Useful Energy Gain
Transparent Cover
Conduction
Absorber

Figure 2-7. Energy Balance of a Typical Solar Collector

Many types of translucent coverings have been used as solar collector glazings, and many criteria exist for materials selection. Generally, however, three areas of concern are significant: physical properties, weathering and durability, cost. The important physical properties include the material's transmittance of short-wave radiation (how much light it allows through), its transmittance of long-wave radiation (whether it traps heat effectively inside the collector), its maximum operating temperature (whether it will withstand high temperatures, especially in stagnation conditions when no heat transfer is taking place), its coefficient of expansion/contraction (whether its expansion rate is manageable), its strength and rigidity, its weight, and its appearance (whether it is aesthetically pleasing).

Weathering and durability are critical to operational life. Will the glazing resist ultraviolet degradation? Does it resist abrasion such as scratching? Will it become brittle with age? Finally, cost is a major consideration in glazing, as in the selection of all solar components.

Many manufacturers continue to experiment with glazing materials other than glass, which is relatively expensive. However, glass remains the most utilized collector covering in this country. Glass is not subject to ultraviolet degradation and has favorable transmissivity. In all cases, collector glass should be tempered, increasing its thermal resistance to breakage and its mechanical strength by a factor of five.

Table 2-1 compares commonly-available types of glass and other collector glazing alternatives.

Early in the solar industry it was found that higher temperatures could be achieved by the addition of double- or even triple-glazings to collectors. Double-glazing became quite popular for domestic water heating and space heating collectors. However, over time this practice has become less widespread. Each layer of glazing has a base reflective loss of approximately 8%. Double-glazing therefore would increase the total reflective loss to approximately 16%. This disadvantage, combined with other constraints such as weight and cost, has led most manufacturers today to look at other methods of increasing efficiency.

Absorbers. In the last few years, collector manufacturers have experimented with marketing glazed collectors with non-metallic absorbers such as polypropylene and EPDM mats. In general, however, absorber plates for liquid systems are made of copper, aluminum, or steel. There are three major considerations governing the selection of absorber plate material: conductivity (thermal performance); ability to withstand high temperatures including stagnation conditions; and durability/material compatibility.

In the majority of liquid solar systems now available, the heat-transfer medium is channeled through riser tubes adhered to the absorber plate. Heat, therefore, must be efficiently conducted to the tubes from all areas of the absorber surface. Copper, being the most conductive material common today, is widely used. To equal copper's conductive performance, an aluminum sheet of twice the thickness of copper is needed. Sheet steel must be nine times as thick as copper to be of comparable efficiency.

Another reason that metals such as copper are appropriate for glazed collector absorbers is their resistance to failure from high temperature. As indicated earlier, any good collector must be able to withstand stagnation. Stagnation may be defined as a collector's upper equilibrium temperature, the point at which a collector, left to bake in the sun with no heat transfer, would begin to lose as much energy as it collects. An efficient collector might have a stagnation temperature in the range of 400° F, a temperature that might be reached easily for extended periods during a power outage when the circulation pump is not energized. All components utilized within the collector casing must be able to endure stagnation conditions.

Table 2-1. Comparions of Glazing Materials

Advantages	Disadvantages
GLASS	
• Excellent Transmissivity Characteristics	• Difficult to Site Fabricate
• Superior Resistance to Heat, U.V., Abrasions	• Low impact Resistance
• Low Thermal Expansion/Contraction	• Cost
• Easily Available	
• Transparent	
ACRYLIC	
• Excellent Transmissivity Characteristics	• Susceptible to Abrasions
• Superior U.V. & Weather Resistance	• High Expansion/Contraction Rate
• Won't Yellow	• Slight Embrittlement with Age
• Lightweight	• Cost
• Easy to Site Fabricate	• Relatively Low Service Temperatures
POLYCARBONATE	
• Excellent Service Temperatures	• Poor Weatherability & U.V. Resistance (Yellows)
• High Resistant to Impacts	• Scratches Easily
	• Not Easily Available
	• High Expansion/Contraction Rate
FIBER REINFORCED POLYSTER	
• Low Cost	• Susceptible to U.V., Dust & Pollution Degradation
• High Strength	• Yellows with Age
• Superior Weatherability-Tedlar coated panels	• High Expansion/Contraction Rate
• only	
• Easy to Fabricate and Install	
LAMINATE: ACRYLIC/POLYESTER	
• Combines Weatherability of Acrylic with High Service Temperature of Polyester	• Non-Reversible
• Good Transmissivity Figures	• Susceptible to Wind Flapping
POLYETHYLENE	
• Inexpensive	• Poor U.V. and Weather Resistance
• Easy to Install	• Low Service Temperature
• Easily Available	• Cats LOVE to Climb on the Stuff

Table 2-1. Comparison of Glazing Materials (Concluded)

Advantages	Disadvantages
POLYESTER	
• Low Cost, Clear Glazing	• U.V. Degradable Unless Treated
• High Service Temperature	• Optical Clarity is Distorted Due to Thinness of Material
FLUOROCARBONS	
• Excellent Weatheability	• High I.R. Transmission
• Strong	• Not Easily Available
• High Solar Transmission	• Susceptible to Wind Flapping
• High Solar Transmission	• Same as Tedlar PVF
• High Service Temperatures	• Poor Tear Resistance
• Long Life	
SILICONE COATED CLOTH	
• Good Transmissivity Characteristics	• Susceptible to Wind Flapping and Tearing
• Excellent Service Temperature	
• Extremely Weatherable	

Finally, absorber plate durability is threatened in any solar system if there is a possibility of corrosion. Corrosion can occur from contact of dissimilar metals (such as aluminum and copper). It can be provoked by a low pH (high acidity) of a water or antifreeze solution inside the system. It is aggravated by corrosive oxygen from air itself and by the relatively high operating temperatures typical of glazed collectors. Copper does resist corrosion more effectively than aluminum and steel, but even copper must be treated carefully in manufacture and maintained properly in the field.

The ultimate performance of a metallic absorber plate is strongly affected by the optical characteristics of its surface. Various dark coatings are placed on absorbers to increase their performance. Table 2-2 compares the absorptivity of solar radiation of different surfaces. (It indicates clearly why blacktop paving is often hot under foot and why outdoor storage tanks are painted white to avoid overheating of the contents.)

Table 2-2. Solar Absorptivity Of Various Surfaces

Black	0.92
Red, Brown, Green	0.73
Yellow	0.60
White, Light Cream	0.40
Dull Metal	0.52
Metallic Paint, Polished Metal	0.40
Highly Polished Metal	0.25

One of the most widely-used finishes on collector absorber plates is a flat black paint over primer. Generally, a high temperature variety with the most durable binder is selected. Carbon black is popular because it absorbs well, is inexpensive and durable. It is important to realize, though, that while absorbing solar radiation, the temperature of the absorber plate will rise and the absorber itself can become an emitter of long-wave radiation (heat). The emissivity of the coating material is expressed as the ratio of the radiating power of the material to that of a theoretical "black body" where emissivity (E) equals 1.0. Carbon black, for example, has an absorptivity and emissivity of 0.95 to 0.98.

In recent years, solar experimenters have found reliable coatings which offer high absorptivity but greatly decreased emissivity. Such coatings, which increase the greenhouse effect by impeding absorber heat loss, are called selective surfaces. Nickel and chromium, for example, can be electroplated onto metallic surfaces in a way that gives a rough surface structure to the plating which appears black. When properly done, the surface will have a pitted microstructure which will tend to inhibit the release of radiation.

Table 2-3 compares the absorptivity and emissivity of popular absorber coatings.

Table 2-3. Characteristics of Absorptive Coatings

Property / Material	Absorptance 1/ α	Emittance ϵ	$\frac{a}{\epsilon}$	Breakdown Temperature °F (°C)	Comments
Black Chrome	.87-.93	.1	~9		
Alkyd Enamel	.9	.9	1		Durability limited at high temperature
Black Acrylic Paint	.92-.97	.84-.90	~1		
Black Inorganic Paint	.89-.96	.86-.93	~1		
Black Silicone Paint	.86-.94	.83-.89	~1		Silicone Binder
Pbs/Silicone Paint	.94	.4	2.5	662 (350)	Has a high emittance for thicknesses >10um
Flat Black Paint	.95-.98	.89-.97	~1		
Ceramic Enamel	.9	.5	1.8		Stable at high temperatures
Black Zinc	.9	.1	9		
Copper Oxide over Aluminum	.93	.11	8.5	392 (200)	
Black Copper over Copper	.85-.90	.08-.12	7-11	842 (450)	Patinates with moisture
Black Chrome over Nickel	.92-.94	.07-.12	8-13	842 (450)	Stable at high temperatures
Black Nickel over Nickel	.93	.06	15	842 (450)	May be influenced by moisture at elevated temperatures
Ni-Zn-S over Nickel	.96	.97	14	536 (280)	
Black Iron over Steel	.90	.10	9		

Black chrome, which is shown to have a fairly high absorptivity and low emissivity, has become common in glazed flat-plate collectors used for water and space heating. The importance of low emissivity becomes increasingly critical with the decrease of the ambient temperatures in which the collector operates. Black chrome has, therefore, largely displaced double-glazing as a technique for improving collector efficiency for cold weather use.

BEST DOCUMENT AVAILABLE

Another important consideration in liquid glazed collector absorber plates relates to the heat removal system, specifically the manner in which the riser tubes are bonded to the absorber plate. The bonding must allow for optimum conduction of heat from the plate into the heat-transfer fluid in the risers. It also must be strong and permanent. For example, the performance of the panel would be destroyed by any separation which might result from the thermal shock of a cool liquid suddenly introduced to a hot absorber.

Some of the typical fluid passageways used today are illustrated in Fig. 2-8.

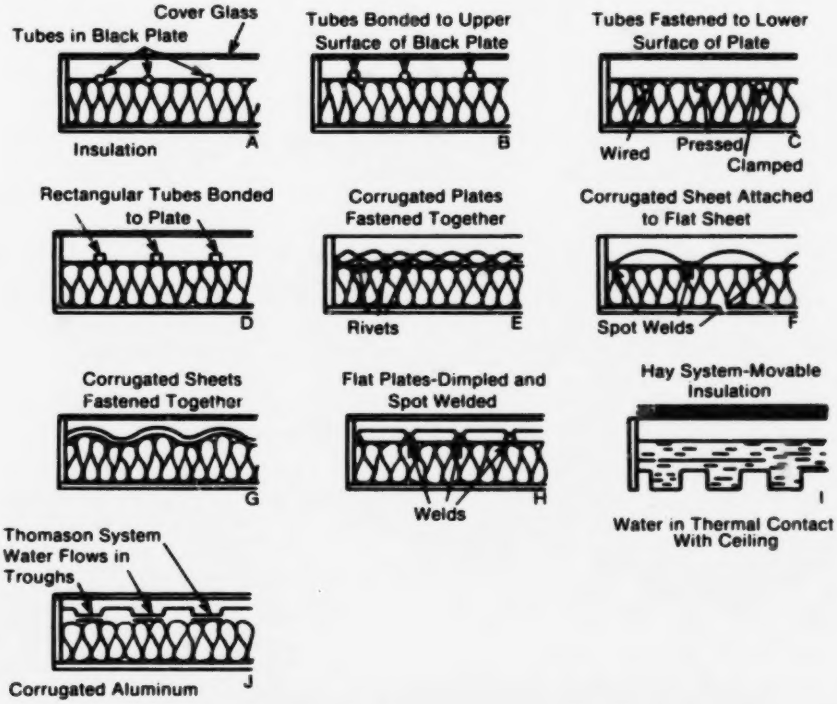
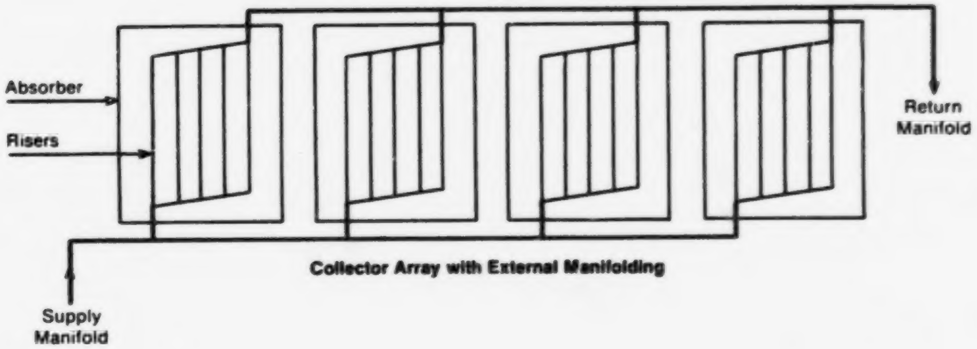

Cover Glass
Tubes in Black Plate
Insulation
A
Tubes Bonded to Upper Surface of Black Plate
B
Tubes Fastened to Lower Surface of Plate
Wired
Pressed
Clamped
C
Rectangular Tubes Bonded to Plate
D
Corrugated Plates Fastened Together
Rivets
E
Corrugated Sheet Attached to Flat Sheet
Spot Welds
F
Corrugated Sheets Fastened Together
G
Flat Plates-Dimpled and Spot Welded
Welds
H
Hay System-Movable Insulation
I
Water in Thermal Contact With Ceiling
Thomason System Water Flows in Troughs
Corrugated Aluminum
J

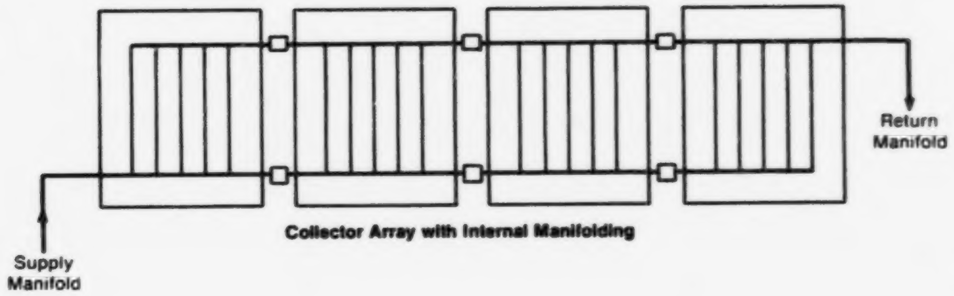
Figure 2-8. Typical Fluid Passageways

A necessary feature for the heat removal system of any absorber plate is the manner in which one collector panel connects with the next. In almost all cases, more than one pre-manufactured collector must be used for pool, water, or space heating. The piping which feeds the heat transfer fluid to the individual risers is the manifold. As shown in Fig. 2-9, there are two types of manifolds common today: external and internal.

In the case of external manifolding of collectors. popular in the 1970s, balanced fluid supply and return to each collector must be piped by the installing contractor. Much site work and materials (piping, fittings, insulation, etc.) are required. More recently, internal manifolding has become favored, as the manifolds are essentially provided by the manufacturer. Collectors need only be joined side-to-side in the field.



Collector Array with External Manifolding



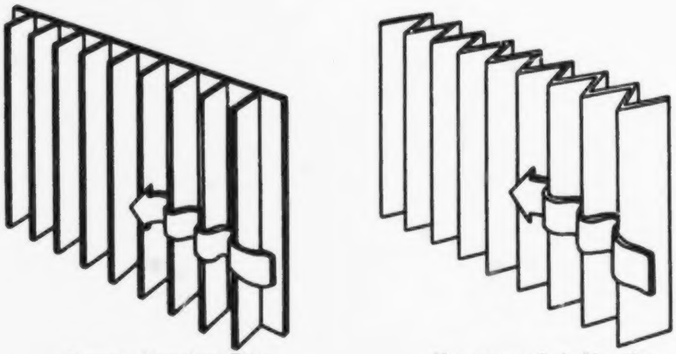
Collector Array with Internal Manifolding

Figure 2-9. Types of Manifolds

It is important to note, however, that in the installation of almost any collector array, "reverse-return" piping should be used. In other words, in both of the configurations above, the fluid supply is properly provided at a lower corner of the array, while the return is taken from the opposite upper corner. This technique will assure balanced flow through all the collectors, since the fluid resistance is virtually the same through any particular manifold and riser path in the array. If the array were piped such that the supply and return were taken from the same end, the collectors farthest away from that end would starve for fluid, thus severely decreasing their efficiency. A recent study by the Northeast Solar Energy Center and the National Association of Solar Contractors, Inc. showed that 29, or 17%, of 170 water heating systems analyzed had been incorrectly installed in this manner.

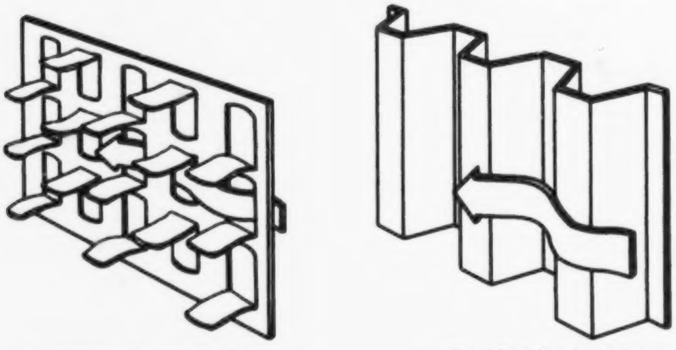
Absorbers in Air Collectors. Solar collection systems which use air rather than liquids as the heat collecting and transporting medium are often used for space heating applications, especially when domestic water heating is considered relatively unimportant. Air collectors are very similar to glazed liquid collectors except that the absorber plate can be much more simple. There is no great concern about leakage from tubes, about material compatibility or thermal shock. In fact, the absorber plate need not even be metal since heat does not usually have to be conducted as it does in liquid systems.

An important concern in air absorber design is that air flow through the absorber plenum be turbulent so that hot air will not become stationary next to the absorber surface. A rough surface with many edges will help to create turbulence and is favored up to the point where too much turbulence is created resulting in too great a pressure drop across the collector. Four typical designs of air absorber plates are illustrated in Fig. 2-10.



Finned Absorber Plate

Vee-corrugated Absorber



Perforated Absorber Plate

Steel-flooring Absorber

Figure 2-10. Air Absorber Plates

Insulation

Essential to the efficient operation of a glazed flat-plate collector is proper installation of insulation. The insulation should cover the perimeter of the panel to reduce edge losses. Even more important, however, is that the entire back of the absorber be thoroughly insulated. Since the rear of the collector usually faces north, it is shaded and the ambient temperature therefore can be relatively low.

A second major consideration in insulation materials for glazed collectors is thermal performance. Most efficient collectors have insulation with an R-value of 10 or more.

The durability of the insulation is another important factor. First, the material must have sufficient structural strength that it will not lose rigidity in the sloping collector case over time. It must not be negatively affected by repeated exposure to water, since many collectors show frequent internal condensation, especially following damp weather. It must be resistant to insects and rodents. And, finally, the material must be able to withstand temperature swings from below zero to stagnation limits.

This latter problem is the most difficult. At temperatures approaching 400°F, many insulators begin to break down chemically and to "outgas". These gases, often potentially toxic, can form on the underside of the cover glazing, seriously reducing transmissivity and thus performance. Common fiberglass insulation, for example, contains phenolic binders to keep it from disintegrating in the installer's hands. These binders, however, break out and outgas unacceptably at typical stagnation temperatures. Polyurethane foam, another good insulator, also tends to outgas at high temperatures and to expand so much that it can be destructive to the collector casing.

With correct treatment, though, fiberglass and urethane have become the most common insulating materials. High temperature fiberglass without binders is available and will work very acceptably, as will urethane when it is properly encased and covered so that outgassing will not reach the cover glazing.

Casings. The final shared component of all glazed flat-plate collectors is the casing. The casing must provide a structurally strong and weatherproof housing for the glazing, absorber, and insulation, and it must provide a method to attach the collector to the roof or stand.

Most glazed collector cases are fabricated from aluminum, though some manufacturers have used steel, wood, fiberglass, and plastic. Whenever wood or steel are used, they must be specially treated to be weather resistant. Plastic surfaces have proven especially successful. Whatever material is used, it must be consistent with the design-life of good flat-plate collectors, which is generally considered to be 20 to 25 years.

The glazing and absorber plate support functions of the casing are complicated by different rates of thermal expansion and contraction of the various materials involved. In essence, both the glazing and absorber must be allowed to float within the casing while at the same time being supported in a weathertight manner.

Often glazing is held in the casing with a U-shaped rubber gasket as shown in Fig. 2-11. The gasket must resist weathering, ultraviolet degradation, and embrittlement.

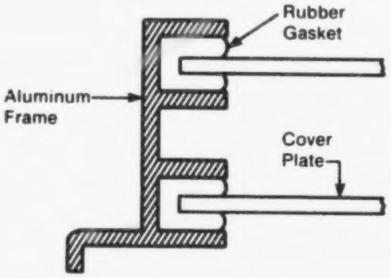


Figure 2-11. Cross-section of Glazing Mounting

The absorber plate, on the other hand, is often laid directly on top of the insulation, allowing free expansion and contraction within the case. It is especially important with metal cases that side insulation provide a thermal break between the expanding absorber and the case to reduce the possibility of significant conductive heat loss.

All of the seams of the case must be tightly closed using durable sealants and hardware that is materially compatible with the case. As indicated earlier, however, even in a properly constructed collector, internal condensation can occur. Condensation is frequently controlled by the placement of small "weep holes" in the case which allow the water droplets to drain down the inner glazing and out of the casing. It is, therefore critical that these weep holes be on the bottom edge of the installed collector.

Flat-Plate Collectors - Performance and Durability Testing

In the 1950s, Hoyt C. Hottel and Austin Whillier at M.I.T. developed an equation to describe the thermal performance of solar collectors. As the industry in this country began to grow and many different collectors were being introduced, the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) used the Hottel-Whillier equation as the basis for a uniform collector testing method. Consequently, a means now exists to compare the actual thermal output of different collectors. The test is referred to as ASHRAE 93-77.

The efficiency of a solar collector can be defined as the usable output of energy divided by the solar energy input.

$$\text{Efficiency} = \frac{\text{Usable output energy}}{\text{Solar energy input}}$$

The problems of determining exact collector efficiencies are considerable because of the many variables involved. The Hottel-Whillier equation attempts to synthesize these many variables by providing a meaningful base for efficiency comparison. This base is expressed as follows:

$$\frac{\text{Collector Inlet Temperature - Outside Temperature}}{\text{Solar Insolation}}$$

or simply

$$E = \frac{T_i - T_a}{H}$$

If the working efficiencies of any collector are determined with this equation using several different conditions, a collector performance curve can be plotted on a graph as in Fig. 2-12.

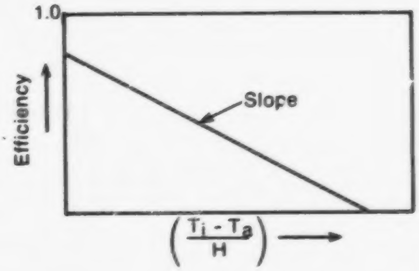


Figure 2-12. The Collector Efficiency Curve

A good example would be the curve of a typical single-glazed, black chrome. flat-plate collector. Three typical Hottel-Whillier "points" can define the curve:

Point 1. A summertime application such as pool heating (Fig. 2-13.) The pool is 75°F (and since pool water would be flowing into the collectors, 75°F would be the inlet temperature), ambient temperatures are 70°F, and a bright summer day is giving solar radiation (insolation) equivalent to 250 Btu ft^2/hr.

$$\frac{75^\circ - 70^\circ}{250} = .02$$

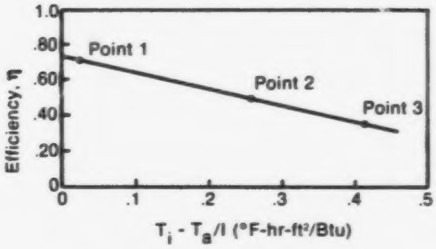


Figure 2-13. Efficiency Graph

The collector tests at approximately 68% efficiency at this point.

Point 2. A typical domestic hot water heating condition. The storage tank (and hence collector inlet) might be 100°F, the ambient temperature is 50°F, and the insolation is 200 Btu/ft^2/hr.

$$\frac{100^\circ - 50^\circ}{200^\circ} = .25$$

The collector tests at approximately 50% efficiency at this point due to the cooler, less sunny conditions.

Point 3. A typical space heating condition. The storage tank (and collector inlet) might be 90° F, the ambient temperature is 30° F, and the insolation is 150 Btu/ft^2/hr.

$$\frac{90^\circ - 30^\circ}{150^\circ} = .40$$

The collector tests at approximately 40% efficiency under these conditions due to decreased insolation and freezing ambient temperatures.

When several such points are connected, the representative curve allows the collector to be analyzed under any normal criteria and to be compared with other collectors in these same conditions. For example, a comparison of Collector A (an inexpensive, single-film glazed, non-selective collector) and Collector B (a double-glazed, non-selective collector) might create the curves shown in Fig. 2-14.

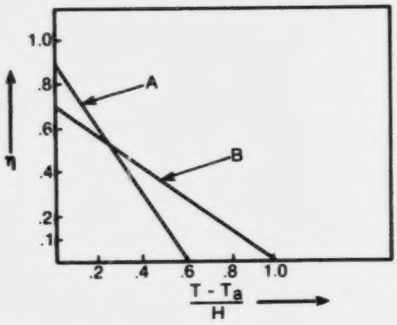


Figure 2-14. Comparison of Collector Efficiencies

Because it is single-glazed (and has half the reflective losses), Collector A would actually outperform the more expensive Collector B in the most favorable solar conditions, such as pool heating or summertime domestic water heating. Collector B, however, proves to be far superior for more difficult conditions as would typically be met in space heating.

A requirement of the RCS program is that all collectors installed under the program be tested by ASHRAE 93-77. Such a test allows the performance of collectors to be compared in relation to their cost and their application, assuring the installation of the most effective equipment.

The HUD Intermediate Minimum Property Standards Supplement (HUD MPS) for active solar systems imposes an additional requirement on the ASHRAE 93-77 test. In essence, it requires that each collector type be tested directly "out of the box". It must then be subjected to a rigorous weather test. The collector must be dry, i.e., be allowed to stagnate with no heat transfer taking place, and it must undergo 30 days cumulative exposure to a minimum insolation value of 1500 Btu/ft^2/day. Included must be a minimum of one consecutive four-hour period with insolation of 300 Btu/ft^2/hr or greater. At the end of the testing, the collector must be able to perform within 10% of its initial thermal efficiency.

The obvious reason for exposing the dry collector to the baking sun, wind, and rain is to identify potential problems with collector materials and construction. Outgassing, insulation warpage, deterioration of absorber coatings, and case deformation are among the many failures which have been identified in stagnation testing. The high initial costs of solar equipment point to the critical need to understand any possible impediment to the long life of collectors.

2.2.2 Transport Systems

The transport system of a solar heating installation is that system which carries the collected heat from the liquid or air collectors to storage. It consists of several components, including the piping or ducts between collectors and storage; the pumps or blowers to move the heat; valves, drains or dampers; the heat transfer medium itself; and often a differential controller and a storage heat exchanger.

The manner in which the heat transport is accomplished has become the major determinant in the classification of solar systems. A number of generic liquid system types is presented below. In each case, the system described will be a solar water heater. More complex applications such as space heaters and combined systems tend to follow the same design concepts.

Thermosyphon System

The oldest and most basic type of solar water heater is the thermosyphon system shown in Fig. 2-15. In strict terms, the system should be labeled passive since, in most cases, no electrical power is used to pump the heat exchange fluid (usually water) through the transport loop. Instead, the system relies on the principle of convection, the natural rising of heat. By positioning a storage tank above an array of collectors and by feeding cold water to the bottom of the tank, cool water from the tank in a properly piped system will descend to the collectors. After heating, it will flow up naturally toward the tank top. Hot water is then drawn from the top of the tank. Theoretically, convective action will not take place when there is no heat to be collected from the panels. Reverse syphoning can be avoided by locating a one-way valve in the system.

Thermosyphon systems are attractive because of their simplicity and relatively low cost. For example, it is estimated that over 90% of the 3,000,000 solar water heaters now in use in Japan rely on the thermosyphon principle. There are, however, concerns about using thermosyphon systems in freezing climates, since water remains at all times in the solar loop. In the United States, these systems are generally utilized only in the warmest climates or in summertime only applications.

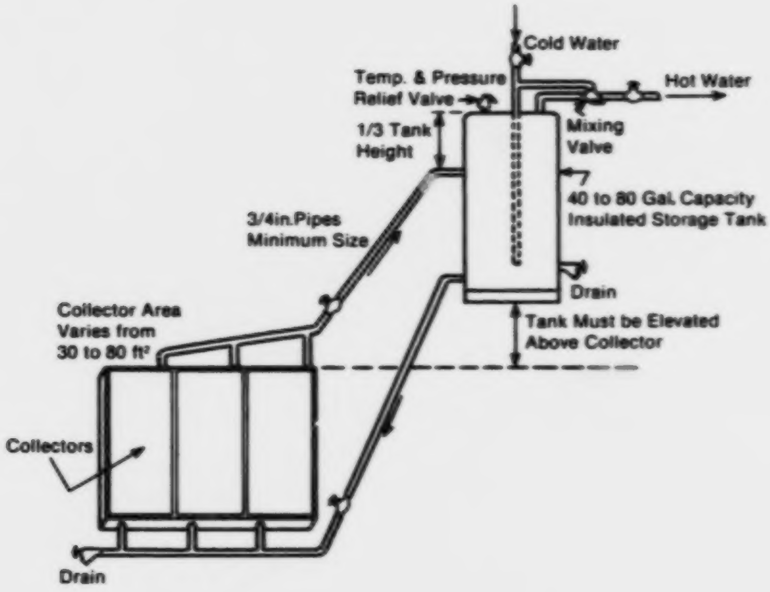

Cold Water
Temp. & Pressure Relief Valve
Hot Water
1/3 Tank Height
Mixing Valve
40 to 80 Gal. Capacity Insulated Storage Tank
3/4in.Pipes Minimum Size
Drain
Collector Area Varies from 30 to 80 ft²
Tank Must be Elevated Above Collector
Collectors
Drain

Figure 2-15. Thermosyphon System

Draindown System

In this country, the solar industry's earliest answer to the problem of freezing conditions was the draindown system (see Fig. 2-16). Like the thermosyphon, the draindown is a direct system in that the same potable water that comes out of the resident's faucets also flows through the collectors when heat energy is available. When energy is not available, the water is allowed to drain completely out of the solar collector loop for freeze protection.

In order to accomplish the draining function, the collectors must be placed above the storage tank; all piping must be properly pitched; a correctly-sized pump must be used; solenoid valves must allow filling and draining; and a solar differential thermostat must determine when the pump should be operating and when the loop should be drained.

Several problems have been experienced with draindown systems over the years. The entire solar loop must be able to withstand city water pressure which can be as high as 100 psi, or pressure reducing valves must be installed. The system must be able to withstand potential corrosion from the alternate exposure to fresh air and untreated water. Most importantly, though, the system's freeze protection is totally dependent on the proper operation of the differential thermostat (or control) and the solenoid valves. These two particular components have been troublesome to the solar industry in the past. In 1976 alone, for example, 19 of the 34 draindown systems installed under the New England Electric System's solar water heating test froze due to malfunctions in the freeze prevention components.

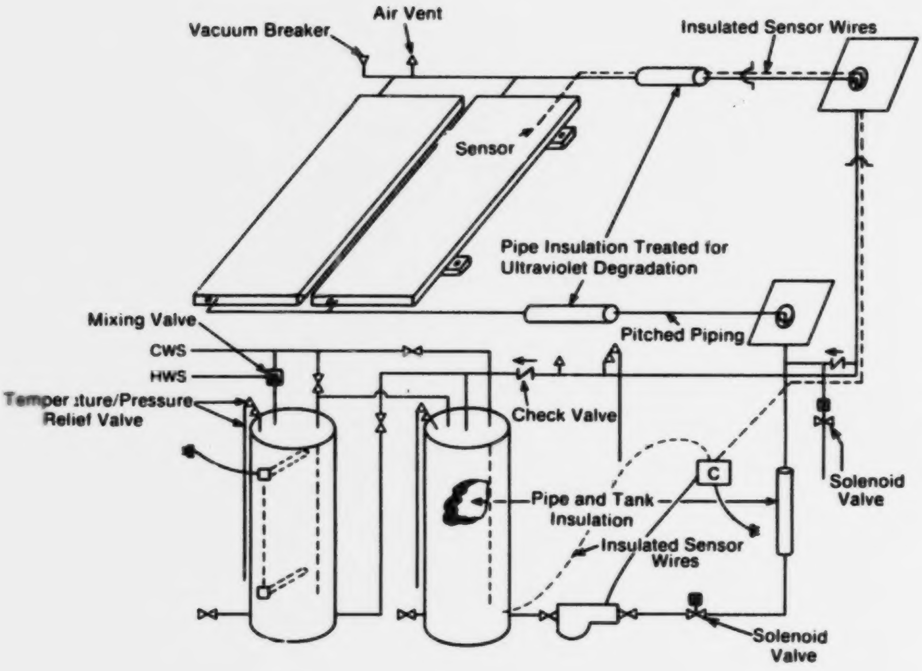

Vacuum Breaker
Air Vent
Insulated Sensor Wires
Sensor
Pipe Insulation Treated for Ultraviolet Degradation
Mixing Valve
CWS
HWS
Temperature/Pressure Relief Valve
Pitched Piping
Check Valve
C
Solenoid Valve
Pipe and Tank Insulation
Insulated Sensor Wires
Solenoid Valve

Figure 2-16. Typical Draindown System

In the past few years, many improvements have been made in draindown configurations and in controllers themselves. Several manufacturers are now offering prepackaged modules which feature all necessary valves and components already assembled. It is likely that greater reliability will be experienced with these newer systems.

Drainback Systems

Largely in response to early draindown failures, another option for freezing climates was developed: the drainback system (see Fig. 2-17). Unlike the thermosyphon and draindown configurations, the drainback system is indirect, which means that potable water itself is not circulated through the collectors. For this reason, a heat exchange must take place.

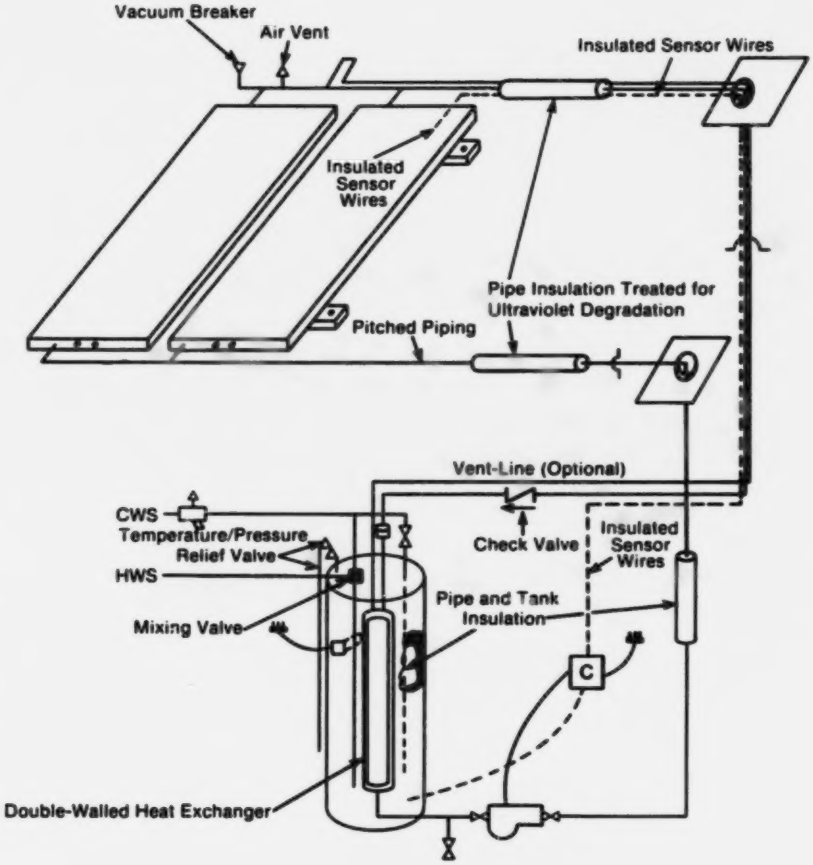

Vacuum Breaker
Air Vent
Insulated Sensor Wires
Insulated Sensor Wires
Pipe Insulation Treated for Ultraviolet Degradation
Pitched Piping
Vent-Line (Optional)
CWS
Temperature/Pressure Relief Valve
HWS
Check Valve
Insulated Sensor Wires
Mixing Valve
Pipe and Tank Insulation
C
Double-Walled Heat Exchanger

Figure 2-17. Typical Drainback System

The drainback system features a holding tank that stores heat and the heat exchange fluid, usually distilled or deionized water. When the controller calls for solar collection, a pump carries the distilled water around the loop and through the heat exchanger to deliver heat to the potable water supply. When collection can no longer occur and the pump turns off, the transfer water drains back into the holding tank by gravity. As with the draindown system, the loop piping must be carefully pitched.

Closed-Loop Recirculation System

Like the thermosyphon design, the recirculation system is a closed loop because the solar loop never drains. When there is heat to be collected, the controller turns the circulator on. When energy is not available, the system shuts down. Its freeze protection comes from recirculation of the heat transfer medium (usually the potable water) whenever ambient temperatures approach 32°F. This circulation is precipitated by the controller which has a frost-cycle sensor.

This type of system is attractive because of its simplicity. However, there are clearly system-efficiency losses whenever heated water from storage must be circulated through cold collectors to prevent freezing. Additionally, freeze protection is completely dependent on the controller and sensor sub-system, as well as the electrical power supply. The liability of failure is illustrated dramatically by an incident in Phoenix, Arizona. On December 8, 1978, the nighttime temperature suddenly and uncharacteristically dropped to 25.5°F. Close to 500 recirculation system collectors suffered damage from freezing because of malfunctioning controllers and improperly mounted sensors.

Some manufacturers are continuing to develop further recirculation packages for freezing climates, and reliability is improving. However, at this time, recirculation systems find greatest popularity in the warmest parts of California and Florida.

Closed-Loop Antifreeze System

The system most widely used for year round solar collection in most parts of the country is the closed-loop antifreeze system (see Fig. 2-18). This configuration uses indirect heating through a heat exchanger similar to the drainback. However, since an antifreeze is used as the heat transfer medium, it is not drained from the system at night. In this closed system, the antifreeze is always in the loop, under slight pressure. A circulator moves the fluid around the loop when the controller indicates favorable collection conditions. Because the loop is pressurized, a pump capable of overcoming vertical head, such as needed in a drainback system, is not required.

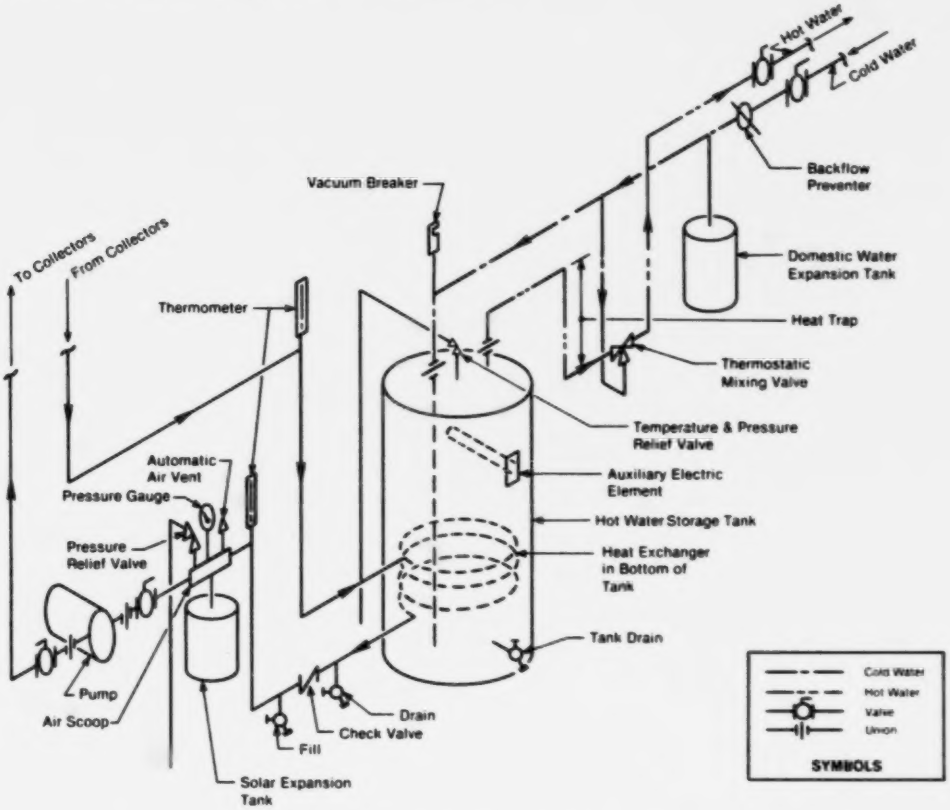

Hot Water
Cold Water
Backflow Preventer
Vacuum Breaker
Domestic Water Expansion Tank
To Collectors
From Collectors
Thermometer
Heat Trap
Thermostatic Mixing Valve
Temperature & Pressure Relief Valve
Automatic Air Vent
Pressure Gauge
Auxiliary Electric Element
Hot Water Storage Tank
Pressure Relief Valve
Heat Exchanger in Bottom of Tank
Tank Drain
Pump
Air Scoop
Drain
Check Valve
Fill
Solar Expansion Tank
Cold Water
Hot Water
Valve
Union
SYMBOLS

Figure 2-18. Single-Tank Closed-Loop System

Although antifreeze systems seem to have solved freezing problems as well or better than other configurations, they too have their disadvantages. First, an indirect system using a heat exchanger, be it drainback or antifreeze, does compromise efficiency. A huge number of variables precludes a general statement on what the loss might be, but solar designers would agree on a figure of roughly 10%. Additionally, the antifreeze itself can present its own series of unique problems which are described in the following sections.

Other Liquid System Configurations

The solar industry in this country is growing so rapidly now that the number of installed systems in many areas is doubling each year. This level of activity typically breeds innovation, and the solar heating field is no exception. In the last year or so, many new system types have been introduced. A good example of a promising alternative is the refrigerant-charged water heater. This unit is similar to the thermosyphon system in that it is essentially reliant on natural convection for heat transfer. However, it features a closed solar loop charged with liquid fluorinated hydrocarbons. Heat is efficiently delivered to a heat exchanger inside the storage tank, taking advantage of a gas-to-liquid phase change. No circulator or controller is required, and many of the problems associated with more conventional heat transfer fluids are avoided.

2.2.3 Heat Transfer Liquids

As indicated above, there are two basic types of heat transfer liquids: water and antifreeze. The decision about which to use is a complicated one which has critical implications for the design of the entire system (see Table 2-4).

Table 2-4. Examples of Typical Heat Transfer Liquids

	Water	50% Ethylene Glycol/Water	50% Propylene Glycol/Water	Silicone Fluid	Aromatics	Paraffinic Oil
Freezing Point, °F (°C)	32 (0)	-33 (-36)	-28 (-33)	-58 (-50)	-100 to -25 (-73 to -32)	—
Boiling Point, °F (°C) (at atm. pressure)	212 (100)	230 (110)	—	None	300-400 (149-204)	700 (371)
Fluid Stability	Requires pH or inhibitor monitoring	Requires pH or inhibitor monitoring	Requires pH or inhibitor monitoring	Good	Good	Good
Flash Point, °F (°C)	None	None	600 (315)	600 (315)	145-300 (63-149)	455 (235)
Specific Heat (73°F) [Btu/(lb.°F)]	1.0	0.80	0.85	0.34-0.48	0.36-0.42	0.46
Viscosity (cstk at 77°F)	0.9	21	5	50-50000	1-100	—
Toxicity	Depends on inhibitor used	Depends on inhibitor used	Depends on inhibitor used	Low	Moderate	--

Water has many advantages as a heat transfer medium. It is inexpensive, readily available, non-toxic, and has favorable heat-carrying capacity (with a specific heat of 1.0). The obvious liability is, however, that a 32°F freezing point requires a draining or recirculation action whenever ambient temperatures are low. Additionally, since water does conduct electricity, it can precipitate galvanic corrosion between dissimilar metal. Therefore, water systems are best piped totally with copper unless an inhibitor is used. In draindown and drainback systems where air is introduced to the system, a bronze or steel pump must be used to help prevent corrosion.

Antifreeze solutions have become increasingly attractive to the industry because of their weather resistance. However, most antifreezes share a disadvantage which is largely overlooked in solar literature. Most have very little surface tension, meaning that these fluids are quite slippery and likely to leak where water might not. In a draindown system, for example, new street or well water with all its impurities, is introduced into the loop whenever there is heat to be collected. The liability is that the impurities of the water can sometimes form scale on the inside of the loop and decrease efficiency. The asset is that a small imperfection in the piping which might cause a leak is likely to be plugged. In an antifreeze system, though, the use of a small amount of a slippery fluid will exaggerate problems of leakage. This concern puts heavy emphasis on the quality of the installation of an antifreeze solar system. Experienced contracting firms have reported that sealing seepage in antifreeze loops is their number one service problem. Careful workmanship and thorough pressure testing of the loop prior to filling with antifreeze are required.

One of the most popular antifreeze solutions now available is the 50%-50% mixture of propylene glycol and water. This solution is favored because it is essentially non-toxic. Consequently, in many states it is allowed to be separated from the potable water with an efficient single-wall heat exchanger. It is inexpensive, has good heat-carrying capacity and will not freeze above -35°F. The major concern with propylene glycol and water, ironically, is not what happens in cold weather but what happens when the fluid becomes overheated, especially in conditions of stagnation. When glycols are raised to very high temperatures, they may begin to break down chemically. Their freeze strength can be reduced, but even more insidiously, they may form organic acids which can be highly corrosive to the copper in the solar loop.

The NESEC/NASC Site Evaluation Report mentioned earlier indicates that 23% of the propylene glycol systems were turning slightly acidic. There appeared to be a significant correlation between acidic antifreeze and systems which were allowed to shut down and stagnate during high temperature conditions. With properly installed and continuously operating systems, propylene glycol does not seem to present a serious problem, but the pH of the fluid should be checked each year and changed when nearing a reading of 6.0. Ethylene glycol, widely known for its role as an automotive antifreeze, has also met wide use in solar heating applications. It is relatively inexpensive, readily available, and features a good heat-carrying capacity and low freezing point. It also appears to be slightly more stable than propylene glycol at high temperatures. The NESEC/NASC study found that only 4% of the ethylene glycol systems tested were becoming acidic.

However, the primary concern with ethylene glycol solutions is that they are generally highly toxic. According to the HUD MPS (p. 6-47) a full double-wall heat exchanger must be used whenever such toxic heat exchange fluids are used. Double-wall heat exchangers, designed to provide optimum protection to the potable water supply, are more expensive and less efficient than the single wall versions that may be used with non-toxic fluids in some states.

Silicone fluids have many advantages since they are quite inert and will not break down even at stagnation temperatures. They have a very low freezing point and will not cause galvanic corrosion. However, the cost of silicone is approximately 3.5 times that of other antifreeze fluids, and its low specific heat (.38) means that larger pumps and more energy are needed to effect proper heat transfer. A more serious problem is that silicone fluids have the least surface tension of all the antifreezes and therefore leak very readily. Utmost skill and special sealing agents are mandatory in the installation of a silicione-charged solar loop.

Aromatic oils are sometimes used in solar heating, but a low flash point tends to make them less safe. They will also dissolve roofing tar which presents problems at many sites if leaking should occur.

Paraffinic oils, which are petroleum-based, are low in cost, nonvolatile, and nonconducting. However, their use is limited because of questions of stability at high temperatures. Periodic replacement is necessary, as they will break down into sludge and become acidic.

2.2.4 Piping and Insulation of Liquid Systems

Selection of a piping material to run between the collectors and the storage vessel relates to material compatibility and operating temperature range. In most solar systems, sweat-soldered copper tubing is used. It is readily available and it is, of course, compatible with copper risers and absorber plates. Certain manufacturers are now supplying collectors with aluminum absorbers and, often, in these systems aluminum piping is used throughout the solar loop.

In collectors which operate at very low temperatures, inexpensive polyvinyl chloride (PVC) piping can be used successfully. For example, in an unglazed polypropylene pool collector system where large amounts of pool water are returning from the array at an upper temperature of approximately 100°F, 2 in. PVC will function perfectly and will maintain its rigidity. However, in most cases, plastic piping is not considered appropriate for higher temperature glazed collectors such as are used for domestic water or space heating. Even the higher temperature CPVC piping will sag badly at 160°F, and polybutylene will deform at approximately 200°F. Whenever these materials are used, they must be carefully anchored, with hangers at 1 to 2 ft intervals on horizontal runs.

Sweat-soldered copper piping is basically unaffected by high temperatures. The only concern is that a high temperature, high strength solder (95-5 tin-antimony) be used on all fittings near a glazed collector array to preclude joint failure in stagnation conditions. Conventional 50-50 tin-lead solder is ordinarily acceptable for other parts of the solar loop. Normal pipe hanging practice, as described by the Uniform Plumbing Code, should be observed.

It is important that all loop piping be sized to ensure proper flow rates, given the number of collectors and the length of the piping run. The following rule of thumb may be used for pipe sizing for solar water heaters where piping runs are less than 40 ft each way:

1/2 in. in diameter (nominal) for up to 2 collectors
3/4 in. in diameter (nominal) for up to 3 collectors
1 in. in diameter (nominal) for up to 7 collectors

In larger arrays such as for pool or space heating or combined applications, conventional hydraulic calculation methods should be used for pipe sizing. To avoid erosion of inside pipe surfaces, flow should not exceed 4 to 8 ft/sec.

In all cases, piping runs should be as short and straight as possible. All draindown and drainback system piping must be pitched downward to permit complete draining at night. All antifreeze systems must be pitched downward, or at least have drains at all low spots, so that antifreeze fluids may be drained for replacement.

Another important, but widely abused, consideration of solar loop piping is insulation. The earliest major field test of active solar systems was the previously mentioned New England Electric Systems monitoring of 100 water heaters. In 1976 this study pointed to the fact that between 20% and 45% of all the energy collected by these systems was being given up to line (piping) and storage losses. To control such losses, the transport loop must be rigorously insulated. The HUD Installation Guideline (p. 47) calls for a minimum of R-4 insulation on all solar piping under 1 in. and R-6 on all piping 1 in. or over.

Table 2-5 describes some of the pipe insulating materials available today.

Table 2-5. Insulating Value of Pipe Insulation per Inch of Thickness

Elastomer	R-3.5
Fiberglass	R-4.0
Phenolic Foam	R-4.3
Urethane	R-6.5
Isocyanurate	R-7.0

It is important to note that this table describes R-value per inch. Many contractors have used elastomer (Rubbertex, Armaflex) on solar loops. The thickest elastomer commonly available is 3/4 in.; therefore this material is insufficient unless at least doubled.

Fiberglass and phenolic foam insulations are popular, especially for inside use. Urethanes are not widely used indoors because they can release noxious gases when burning. Often local building codes preclude their installation unless separated from the living space by a fire wall.

Outside insulation of solar piping presents its own problems. First, the insulation must be very carefully sealed. A small crack anywhere in the covering may worsen over time, allowing the entry of rain water. This water may follow the pitched piping into the building, soaking the loop insulation and rendering it thermally useless.

Second, all outside insulation must be able to withstand exposure to ultraviolet light. Unless treated with paints every three years, elastomer insulations, for example, embrittle, crack, and crumble in the sun. Field studies consistently have pointed to this sensitivity as a major problem.

The favored technique for outside solar piping is the use of metal-cladding or an ultraviolet inhibiting PVC jacket. Preformed urethane corners are available for covering pipe fittings. Mastic materials and silicone sealant work well as pliable but durable seals for all seams.

2.2.5 Storage for Liquid Systems

Because of the intermittent nature of solar radiation, most typical solar heating systems must be capable of storing collected energy until it is needed. The most common storage medium in active liquid systems is water. Water is widely used to store heat from liquid systems because it is inexpensive and readily available, because it has good heat transfer characteristics, and because it has the smallest space requirement of any of the common storage media.

The simplest type of storage is exemplified by the solar swimming pool system. As the pool water is circulated through the collectors, the swimming pool itself becomes the storage tank. This direct relationship, as well as the low temperature involved, adds to the high efficiency of pool systems that was discussed earlier.

Domestic hot water systems generally use storage vessels similar to conventional hot water tanks. Such tanks are manufactured using techniques and materials standardized over many years. Stone-lined steel, glass lined steel, high temperature fiberglass, and galvanized steel are all common materials for these tanks which generally come in 66, 80, and 120 gal sizes. It is very important with storage vessels, as with other solar components, that only high-quality materials be used to ensure a long safe lifetime.

In many parts of the country where hard water is found, stone-lined storage is common. Such steel vessels are coated internally with an inch or so of hydraulic cement which provides excellent longevity even in contact with water impurities.

The majority of domestic water storage tanks used with thermosyphon, draindown, and closed-loop systems are filled with the potable water from the street or well supply. These tanks are, therefore, pressurized and require conventional temperature/pressure relief valves. Drainback systems, however, can use unpressurized tanks. The water level in these unpressurized tanks requires occasional checking and augmenting to compensate for evaporative losses. It also is wise to monitor the chemistry of the water, which is preferably distilled or deionized, because it can change after a year or two of system operation.

Because solar space heating systems must satisfy a larger heating demand than solar water heaters, they usually have more collector area and larger storage vessels. In small applications, a common approach is to connect a number of 120 gal water heater-type storage tanks. In larger systems, a wide variety of unpressurized liquid storage tanks is available (see Fig. 2-19). These larger tanks present a range of considerations, not the least of which is a structure strong enough to support such a vessel. For example, a filled 1000 gal storage tank weighs considerably more than four tons. (The water alone, at 8.33/ lb 1 gal, could be 8330 lb). This weight may be too great for the average home's basement flooring.

Table 2-6 compares several common types of space heating storage. In any type of storage vessel, be it a swimming pool, water heater, or site-fabricated liquid container for space heat, care must be taken to optimize the storage in gallons to the size of the collector area in ft^2. The tendency early in the solar movement was to specify very large storage. A dramatic example was the MIT Solar House I which utilized 360 ft^2 of collector area feeding 17,400 gal of storage. The system worked admirably, largely by

Table 2-6. Common Types of Space Heating Storage

Advantages	Disadvantages
STEEL SHELL	
• Readily available • Light weight • Readily tapped • Relatively low cost • Simple fabrication • Available in bolted form • No capillary water seepage	• Interior corrosion problems unless lined • Exterior corrosion problems in underground service • Access room for retrofit and replacement • Low resistance to underground loads without extra material
ALUMINUM SHELL	
• Light weight • Readily tapped • Simple fabrication • No capillary water seepage	• Interior corrosion problems unless lined • Exterior corrosion problems in underground service • Access room for retrofit and replacement • More difficult welding than steel • Higher cost • Low resistance to underground loads without extra material
REINFORCED CONCRETE	
• Readily formed into any shape or size • Corrosion resistant • May be formed in place for retrofit situations • Greater resistance to underground loads • Relatively low cost • Mass may be used as a heat store • Readily available on a local basis	• Heavy • Water seepage through cracks and via capillary water unless lined • Leakage at joints in precast form unless lined • Requires sophisticated design and workmanship • More difficult to tap
REINFORCED PLASTICS	
• Light weight • Interior and exterior corrosion resistance • Water tightness • Readily tapped	• Sophisticated design, fabrication, and test process • Lower temperature resistance • Low resistance to underground loads without extra material • Higher cost • Less availability than steel or concrete

Table 2-6. Common Types of Space Heating Storage (Concluded)

Advantages	Disadvantages
PIPE SECTIONS (asbestos cement, fiberglass or lined steel in vertical orientation)	
• Readily available • Requires less impact on building area • Readily adapts to retrofit situations • Corrosion resistant • Readily tapped	• Foundation weight • May cost more than steel or concrete as presently produced • Low capacity in practical lengths unless vertically oriented
WOOD	
• Readily available • Light weight • Relatively low cost • Adaptable to retrofit situations with limited access • Corrosion resistant	• Capillary water seepage unless lined • Above ground service only • More difficult to tap
ELASTOMERIC FABRICS	
• Readily available • Adaptable to low height situations • Light weight • Corrosion resistant	• More difficult to insulate • May have limited temperature capability unless fabricated with proper synthetic rubber • Limited applications, cannot be used underground

storing the summer's energy in the well-insulated tank and distributing it in winter. In fact, in two years (1939-1941) the storage temperature was never lower than 125°. However, the vast storage capacity may seem somewhat disproportionate today when it is realized that the entire heated floor area in the house was only 500 ft^2.

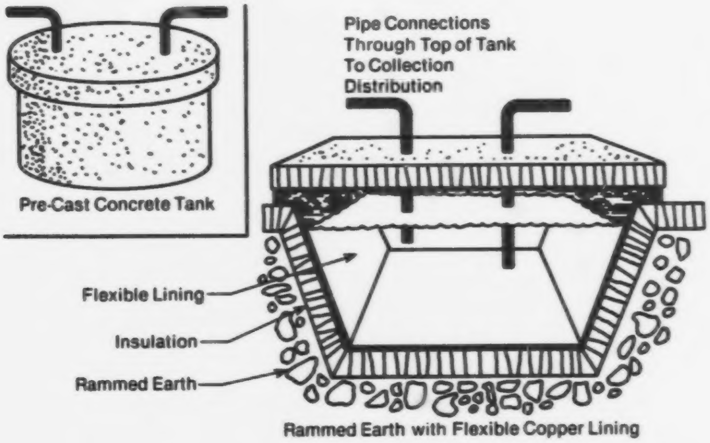

Pre-Cast Concrete Tank
Pipe Connections Through Top of Tank To Collection Distribution
Flexible Lining
Insulation
Rammed Earth
Rammed Earth with Flexible Copper Lining

Figure 2-19. Typical Unpressurized Space Heating Storage Tanks

Issues of cost and physical size have led contemporary solar designers to decrease storage volume relative to collection area. The implications are, however, that at certain times the smaller storage will be insufficient to meet the demand for heat. On the other hand, the smaller storage size will allow the system to be much more responsive in periods of sunshine. Most design solutions today call for ratios of 1 to 3 gal of storage per ft^2 of collection area. There are many criteria, however, and it is of paramount importance to follow the recommendations of the solar manufacturer.

Regardless of storage type or size, the lessons of the New England Electric System solar program must be remembered. The tank must in every case be thoroughly insulated on the sides, top, and bottom. A simple frame of reference is provided by a comparison: if a solar storage tank, placed in a 50°F basement, has been heated to 140°F on a sunny day, the heat loss conditions of the tank would be the same as those for the heat loss from a home heated to 65°F on a night that is 25°F below zero. The HUD Installation Guidelines (p. 49) call for a minimum of R-11 insulation on all storage vessels, but most conscientious solar designers and contractors prefer an R-value of 20 or more.

2.2.6 Pumps for Liquid Systems

The pumps used with most liquid systems are electrically-operated centrifugal circulators, generally of low horsepower. A typical size for a solar water heater, for example, would be between 1/4 and 1/25 of a horsepower. Pumps, like collectors, controllers, tanks, and other major components, are typically supplied by the manufacturer as part of the solar package.

Two central considerations in the selection of a proper pump are flow rate and head pressure. Flow rate is the number of gal/min of heat transfer fluid which is required to flow through the collectors, a number that is supplied by the collector manufacturer. Typical rates might be .015-.04 gal/min/ft^2 of collector absorber.

Head pressure is the fluid resistance the pump must overcome. It is the total of static and friction head losses. Static, or vertical, head refers to the height the fluid must be piped. For example, in a drainback system, each morning the pump must move the heat transfer water from the holding tank up to the top of the collectors. Head pressure is measured simply in feet of vertical rise. One foot of water is equal to 0.43 psi. Friction head losses refer to the pressure losses caused by friction between the transfer fluid and the piping in the system. The pressure drop (or resistance) for all components (collectors, valves, fittings, etc.) can be calculated by consulting standard plumbing tables.

By comparing the required flow rate with the static and friction head, the proper pump is selected. Figure 2-20 shows curves for two pumps. It demonstrates that a pump's capacity decreases as total head increases.

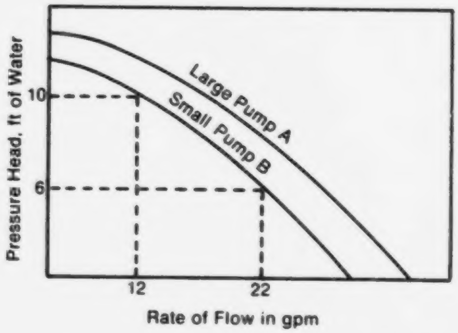


Figure 2-20. Pump Characteristics

The other major factors in selecting a solar pump relate to the type of system being used. In closed-loop systems, i.e., systems not open to the atmosphere, an iron pump is generally adequate. The pump can usually be small, since essentially only friction head need be overcome. Because closed-loop systems are pressurized, the supply lift to the collectors is counterbalanced by the return drop thereby reducing the pumping power required.

Rules for pump selection for open-loop systems are more stringent, however, because the presence of air in the system can cause corrosion thus reducing pump life. Bronze or stainless steel pumps are normally used to prevent corrosion. Also, vertical head must be carefully calculated.

A final consideration is that transfer fluids other than water will impact pump selection. Fluid viscosity can vary with friction head, and specific heat can affect flow rate. For these reasons, silicone fluids require about 2.5 times the pumping power of glycols.

2.2.7 Heat Exchangers for Liquid Systems

A heat exchanger is used to transfer heat from one fluid to another, usually across an enlarged surface area. In certain solar systems, such as drainback and closed-loop antifreeze, a heat exchanger is required between the heat transfer medium and the storage medium. The exchanger can be built into or around the storage vessel, or it can be a separate unit. In applications such as space heating, a heat exchanger is commonly required between storage and the distribution medium.

A great number of heat exchanger types exist. Figure 2-21 illustrates four typical liquid-to-liquid heat exchangers and one liquid-to-air heat exchanger such as might be used with residential warm air space heating.

As with all solar components, the selection of a proper heat exchanger depends on the nature of the entire system. Factors such as material compatability come into play, as does the fact that toxic heat-transfer media always require double-wall heat exchangers. The selection and sizing of the exchangers are usually the task of the solar manufacturer who uses computer programs with input for specified flow and temperature conditions.

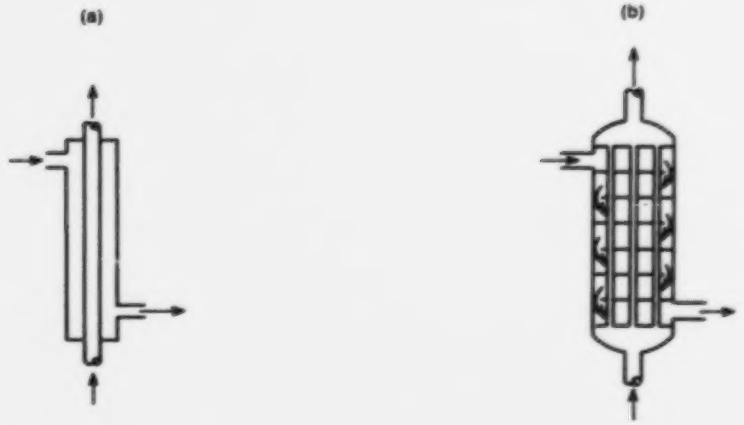
2.2.8 Solar Controllers

The controller may be thought of as the brain of a solar system. It constantly monitors the temperature at the collectors and at storage. This monitoring is made possible by sensors which typically detect temperatures across a thermister chip. The sensors are connected to the controller with two-conductor wires carrying low DC voltage. As the temperatures fluctuate, electrical resistance values will change, and the controller's factory-set circuitry will relay a signal to turn the pump on or off.

When the collector sensor reads 20° warmer than the tank sensor, usually there is solar heat to be collected, and the controller will activate the pump. When the temperature differential decreases to 3° at the end of the day or in cloudiness, the controller will shut the system down, as continued operation would be thermally meaningless or wasteful.

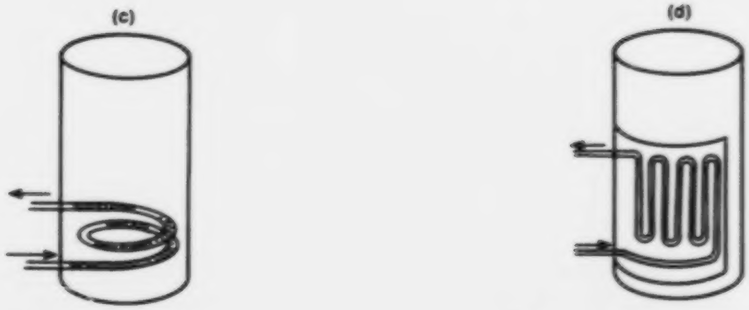
The controller and sensor system is largely the same in hot water, pool, and space heating systems, although certain controllers may offer special features. Some will accommodate high limit shut-offs for system shut-down when storage temperatures reach a maximum desired limit. Others will accommodate frost-cycle sensors, which are required for recirculation systems. Other more complex combinations are often required for multi-purpose solar applications.

As indicated earlier, solar controllers have historically been noted for poor reliability. At one point in 1977, an informal industry survey revealed a 29% failure rate. There is evidence that this situation has improved dramatically. In the recent NESEC/NASC Site Evaluation Program, 89% of the controller systems had never reported problems and were working as designed. Speculation within the industry is that much of the cause of the high early-failure rate was lack of understanding and poor technique on the part of installing contractors. With their integrated circuitry, controllers are delicate devices which need to be handled with great care. It is also very important that all sensors be properly mounted on the collector or tank and insulated so that they will read only the specific temperature that they are designed to measure. The sensor wire must be run very carefully. Since it operates at such low voltage, sensor wire must, for example, be



(a) Concentric Tube

(b) Shell and Tube



(c) Within Tank Exchanger

(d) Traced Tank Heat Exchanger

Figure 2-21. Some Common Liquid to Liquid Heat Exchanger Designs

kept clear of fluorescent lights. If this is not done, the wire might well pick up magnetic conduction (free electricity) which would feed inaccurate resistance information to the controller. Nor should the wire be hastily stapled. In one often-cited installation, a solar installer spent days trying to solve a controller malfunction. Finally, it was found that a sensor wire stapled to the garage had been punctured. Every time the homeowner came home and opened the garage door, causing the structure to move a tiny bit, the wire would short-circuit, and the controller would shut off.

As they should with other solar components, installers of controllers are urged to follow the precise instructions of the manufacturer in order to avoid system failure. No equipment can be mismatched. All service personnel should be equipped with electrical multi-testers and the specific resistance figures for the control/sensor combination used.

2.2.9 Solar Systems Using Air

The distinguishing feature of "air" systems is that air itself is used as the heat transfer medium. Air is forced through specially designed collectors (refer to "Absorbers in Air Collectors" above) and is heated. The heated air is transporated through a ductwork loop in the building to a storage system, usually consisting of a bin of rock. Storage is direct, in that a heat exchanger is not required. The system is controlled by a differential thermostat and sensors analogous to those used in liquid systems. The pumping power in the solar loop is provided by an air blower.

As presented in Table 2-7 there are distinct advantages and disadvantages to using air rather than a liquid as the heat transfer medium.

A number of the considerations detailed above revolve around the thermal characteristics of water. Air is much less dense than water, some .075 pounds per cubic feet as opposed to water at 62.5 pounds per cubic feet. Additionally, the heat carrying capacity of air, its specific heat, is .20, five times less than water at 1.0. For these reasons, relatively huge quantities of air must be moved through a solar system. In fact, approximately 4,000 ft^3 of air are required to match the heat transporting capacity of one cubic foot of water.

It follows, therefore, that with air systems a larger collection area is required, and the ductwork loop must be much larger than a liquid system's loop piping. Generally, the ductwork transport in an air system must be carefully sized to allow a flow of approximately 2-3 Standard Cubic Feet per Minute (SCFM) of air per ft^2 of collector area. Therefore, if a 400 ft^2 collection system is used, the total system SCFM might range from 800 to 1200 SCFM. In many residential applications a duct area of 3 to 5 ft^2 is required.

A further concern with air transport is that the large surface area of ducts allows significant heat loss if not rigorously insulated. Also, although air leakage from a duct might not cause the damage that a leaking liquid can, any loss of the transport air will comprise collection efficiency. A small crack in a seam can be serious, since the air flowing through the system is under pressure.

Table 2-7. Comparative Advantages of Air and Liquid Systems

	Air	Water & Antifreeze
Collection:	• Air collectors can be simpler, less expensive • Air will not boil, corrode, freeze	• Smaller collector area can be used
Loop:	• Will not cause damage with leaks • Heat transfer medium is free of cost	• Good specific heat allows small volumes to convey large heat load
	• Heat transfer medium is free of cost	• Less pumping power is required
Storage:	• Is usually rock but can be water or phase-change material	• Can be water or phase-change material
	• Rock will not corrode tanks, as water can • Rock will not freeze or boil	• Water can occupy 2-1/2 times less volume than the equivalent storage of rock
	• Rock has more defined temperature stratification than water	• Water will not cause dust or allow for growth of insects or fungus
Domestic Water Heating:	• Will not ever contaminate water	• Much better heat transfer properties • If a heat exchanger to potable water is required it will be much smaller than with an air system

The large amount of space required by air ducts and the extreme care needed for their installation often limit the applicability of solar air systems to existing buildings. Most of the air systems being installed today are part of new construction, when architects and contractors can carefully plan for and schedule the loop installation.

A final consideration in air loops is that it is always important to keep the inside of the collector as clean and dust-free as possible. Any debris on the underside of the glazing could seriously decrease light transmission and, therefore, collector performance. A high quality filter must be installed in the ductwork and kept clean.

Although a great deal of interesting work is being done with phase-change materials for storage, by far the most common storage medium for air systems is rock. The thermal characteristics of rock require a very different approach than with water storage.

Table 2-8 compares the heat storage properties of certain solid and liquid materials. A comparison of heat unit capacities (which is the specific heat of a material multiplied by its density) indicates that solid materials such as rock require much more volume to store heat than do liquid materials such as water. Additionally, solid storage materials must have internal air circulation to permit heat transfer. A typical ratio is 70% solid to 30% space. It follows, therefore, that a 30% voided rock storage with a unit heat capacity of 25 would have to be 2-1/2 times larger than water at 62.5.

The rock actually used for storage is often granite or some other clean crushed rock of approximately 3/4 to 1-1/2 in. in diameter. The containers are typically fabricated by either pouring concrete into forms; constructing sturdy walls with studs, plywood and insulation; or, by building up cement blocks with the holes filled with concrete. It is important that the rock not only be carefully cleaned but that it be evenly introduced into the container so as to allow balanced air distribution and to reduce any side wall stress. Weight is a consideration: a 3 x 18 ft cylinder would contain approximately 6 tons of crushed rock. Finally, the container must be waterproofed to prevent any possible penetration of water. A warm, moist container would invite fungus and insects.

Table 2-8. Comparison of Heat Storage Properties

	Specific Heat (Btu/Lb °F)	Density (Lb/Ft^3)	Unit Heat Capacity Btu/Ft^3/°F	
			No Voids	30% Voids
Water	1.0	62.5	62.5	(62.5)
Water (30%)-Ethylene Glycol (70%) Mixture (230° F)	.8	64.1	51	36
Scrap Iron	.112	489	55	38
Magnetite	.165	320	53	37
Scrap Aluminum	.215	168	36	25
Concrete	.27	140	38	26
Rock (Basalt)	.20	180	36	25
Brick	.2	140	28	20
Rock Salt (NaCl) (30%-70% by weight at 230° F)	.219	136	30	21

Figure 2-22 profiles a typical temperature stratification of a rock bin.

The layered nature of heat in properly constructed rock storage containers allows the heated air from the collectors to deposit heat in the upper few feet of the bin, while cool air returns to the collectors from the bottom for further heating. Conversely, when heat is taken from storage for use in the building, the flow direction is reversed. Hot air is taken from the top end of the bin, heated to within a few degrees of the actual rock temperature, while the cooler return air is fed to the bottom of the bin. In either case, as Figure 2-22 shows, it is important to fabricate above and below the rock an air plenum that will permit a uniform flow of air.

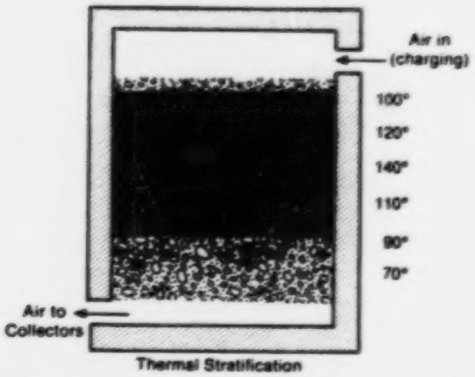


Figure 2-22. Temperature "Layers" in Pebble Bed Storage

The selection of a blower to move air through a solar loop is analogous to the selection of pumps, described earlier. The required horsepower is equal to the system flow rate times the total system pressure drop. As mentioned previously, large amounts of air must be circulated. Also, a pressure drop exists both through the collectors and the storage container. Generally, therefore, significantly greater blower horsepower may be needed than pump horsepower with a liquid system. This greater energy requirement for propulsion will, of course, result in higher operating costs.

2.3 SOLAR DOMESTIC HOT WATER SYSTEMS

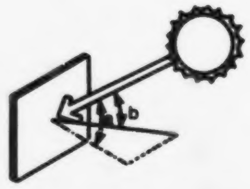
2.3.1 Overview

Solar domestic hot water systems have always been among the most popular applications of solar heating, both in this country and abroad. In certain areas of the United States, there are currently nine water heaters being installed to one of any other active solar system. The predominant reason for this popularity is that water heating is a constant, year-round energy demand. Homeowners take as many showers and wash as many clothes and dishes in January as they do in August. Ability to use collected solar heat not only during the winter months but also during the hot, sunny, summer months contributes greatly to the cost-effectiveness of this type of solar application.

2.3.2 Siting

As with all solar systems, two issues are of paramount importance in siting solar water heaters: orientation and tilt angles. Orientation and tilt angles both refer to the need to place the collectors as perpendicular to the sun as possible, so that the maximum amount of solar radiation can be captured. Figure 2-23 illustrates the compromise in changing the angle of incidence from 0°, which is perpendicular.

Incident Angle (degrees)	Solar Intercepted (percent)
0	100.0
5	99.6
10	98.5
15	96.5
20	94.0
25	90.6
30	86.6
35	81.9
40	76.6
45	70.7
50	64.3
55	57.4
60	50.0
65	42.3
70	34.2
75	25.8
80	17.4
85	8.7
90	0.0



Angle a = Angle of Incidence
Angle b = Altitude Angle

Figure 2-23. Percentage of Radiation Striking a Surface at Given Incident Angles

In order to place a collection array as perpendicular as possible to the sun, it is necessary to remember that the earth rotates daily on a 23.47° tilt in the course of its annual orbit around the sun (see Fig. 2-24).

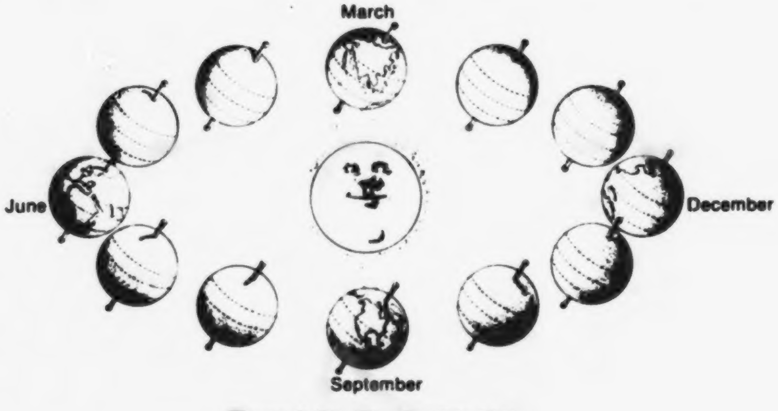
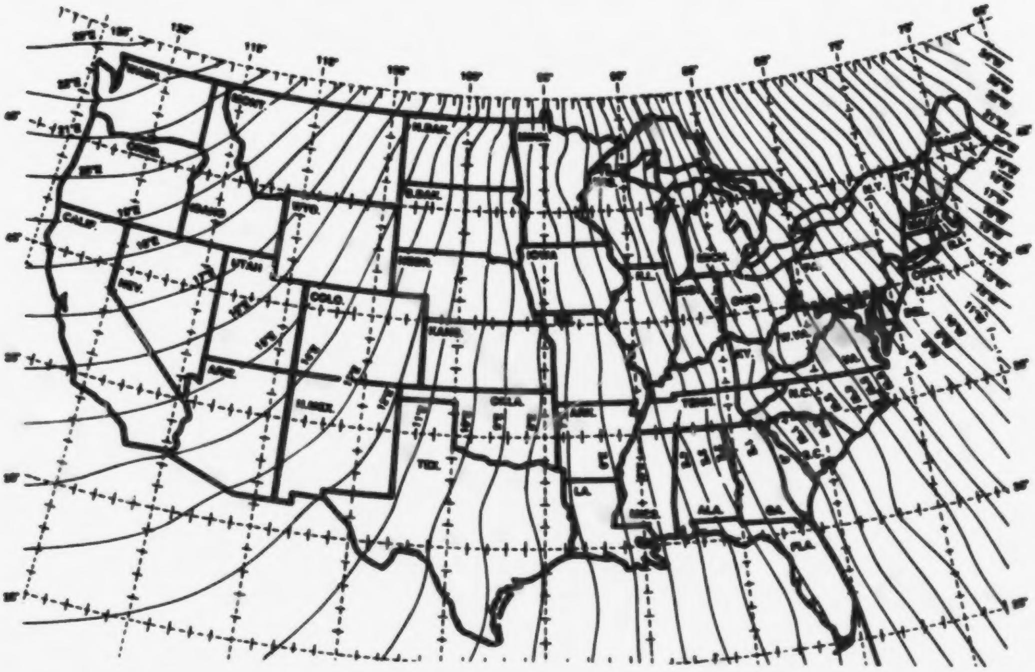


Figure 2-24. The Earth's Tilt

A first consideration would be that to collect solar energy in the northern hemisphere during any time of the year, collectors would have to face south. (By the same token, collectors in the southern hemisphere would always have to face north.) This directional placement of collectors is called orientation.

For optimum performance, solar water heating collectors should face true south. True south is found by locating magnetic south (which is 180° on a compass) and correcting for isogonic deviation. Since the earth's magnetic field is not parallel with its north-south axis, a correction will be required in most parts of the country. The isogonic chart which follows (Fig. 2-25) details the corrections. It demonstrates that in New Orleans, for example, true south is 6° E of 180° or 174° on the compass, whereas in New York City, true south is 12° W of 180°, or 192°.

Although true south placement of solar collectors is most desirable, any orientation within 15° either east or west of true south shows little deviation in system performance and is termed a preferred orientation under RCS. In certain cases, typically in southern locations with low tilt angles and in situations where summer performance is more important than winter performance, an orientation within 45° of true south is acceptable under RCS. Figure 2-26 illustrates theoretical performance compromises in water heaters that deviate at various degrees from true south. In cases of systems oriented 15°-45° from south, the addition of collector area will sometimes bring performance back to a desired design level, depending on the size of the original collector area.



Source: Redrawn from the Isogonic Chart of the United States, U.S. Department of Commerce, Coast and Geodetic Survey, 1965.

Figure 2-25. Isogonic Chart of the United States

The second solar system siting principle, tilt, refers to the angle at which the collection area is slanted from a horizontal position. In order to be as perpendicular as possible to the sun, collectors must be tilted appropriately. A solar space heating system, utilizing the winter sun low in the sky, would need to be sharply tilted. On the other hand, a swimming pool heater, using the high summer sun, would be placed on a much shallower angle. For water heating, a year-round average is normally desirable. Figure 2-24 illustrates that in March and September, the earth is halfway in its orbit around the sun. Therefore, if a collector is tilted so that it will be perpendicular to the sun at noontime on the equinoxes, March 21 and September 21, it will average out the annual sun angles.

The equinox angle is easy to calculate, because it is always the same as local latitude. From the latitude bands in Fig. 2-25, it can be determined, for example, that a solar water heating collector in Tulsa, Oklahoma should be tilted at 35°, while one in Portland, Oregon might be at 45°.

As with orientation, however, tilt angles do allow certain leeway. The RCS program suggests the tilt be 10° plus or minus local latitude. It can be said, fairly, however, that latitude minus 10° would favor collection in the winter months.

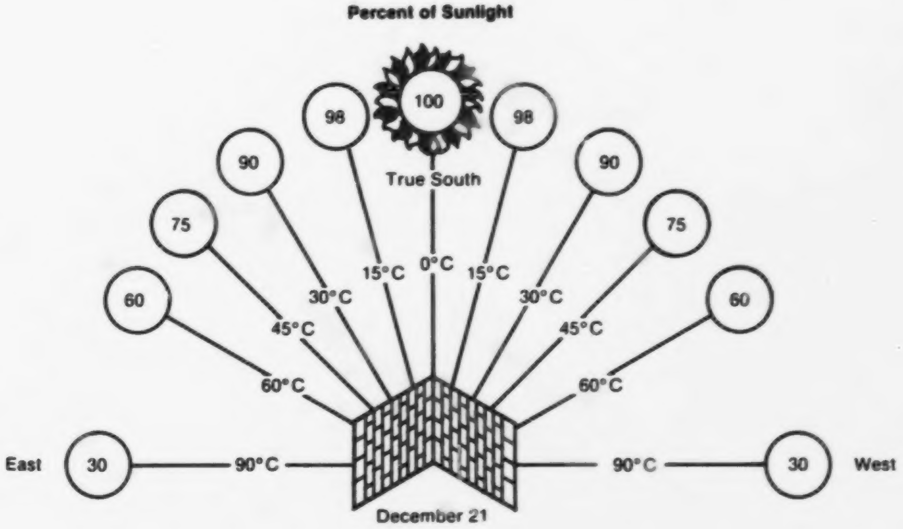


Figure 2-26. DHW Performance Compromise

2.3.3 Sizing

There are two essential steps in sizing a solar water heater or, in fact, any type of heating system. First, it is necessary to compute the number of heating units (Btu) needed to satisfy the demand. Second, the Btu output of the various system options must be calculated, and a configuration chosen to meet this demand.

Analyzing Demand

In order to compute the Btu a household will require for water heating, the gallons of hot water used per day must be estimated. If there is reason to believe that a given household's usage is unusually high (dishwasher, hot tub, frequent car washes, etc.) or low, (absence of the above), the table presented in Appendix A.6 can be used to estimate the specific number. However, if the water usage appears typical, a figure of 20 - 25 gal of hot water per person per day can be used. As an example, consider a normal home with three people in the northern part of the country. It can be assumed that the daily demand for hot water will be 60 - 75 gal.

The next step is to convert the gallons used into Btu required. A Btu is the amount of energy required to heat one pound of water 1°F. There are 8.33 lb/gal of water. For the sample home of three, therefore, the daily demand of 60 gal is multiplied times 8.33 lb/gal.

Since a Btu is equivalent to only a 1° temperature rise, it is necessary to compute precisely how much of an increase in temperature is required. This is accomplished by subtracting the average temperature of incoming cold water from the hot faucet (or delivery) temperature. Incoming water temperatures of 55°F are typical in many northern parts of the country; delivery temperatures of 120°F are widely used. The needed temperature rise, in this case, would be 65°F.

Therefore, the annual Btu demand for hot water for the sample family of three can be computed using the following equation:

$$60 \times 8.33 \times 65 \times 365 = 11{,}857{,}755$$

where

60 = gal used per day
8.33 = lb/gal of water
65°F = temperature rise required (120°F minus 55°F)
365 = days in a year
11,857,755 = net Btu needed for hot water per year

Sizing Collectors

The next step in the sizing process is to determine the number of collectors necessary to accommodate this Btu load. As a rule of thumb, one can often suggest 20 ft^2 of collector per person. Two, three, and four-collector systems are therefore commonly seen around the country.

To continue the above example, however, the collector manufacturer would have to be relied on to tell how many Btu his collector would be able to produce given the location and site characteristics of the typical home with three people. Most manufacturers have solar computer programs for sizing which can handle a wide number of variables, and this information should be readily available.

It is likely that a manufacturer would say that the sample household could expect to receive a net of 130,000 Btu per ft^2 of collector per year, or 7,800,000 Btu with three 20 ft^2-panels. However, it must be made clear that system losses are important. Any system can perform better or worse than this average depending upon the quality of the installation, materials and workmanship, and the specific demands for hot water.

Continuing the example, 7,800,000 Btu would therefore be provided toward a demand of 11,857,755 Btu. This would provide a solar contribution or solar fraction of 65%. Three panels would, in this case, be a near-perfect size. The sizing goal of a typical solar system is to provide a solar contribution of between 50% and 70%. Additional solar contribution usually is not cost-effective due to the law of diminishing returns (see Fig. 2-27).

When all the work necessary to design and install a solar system is performed and a contribution of less than 50% is attained, the system often will not be providing enough heat to make it an attractive investment. On the other hand, if over 70% annual contribution is achieved, during much of the year the system will be producing more heat than can be used. This extreme also decreases the investment efficiency of the system.

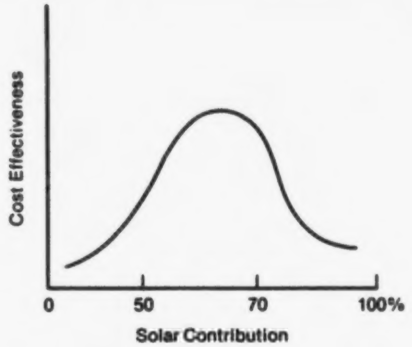


Figure 2-27. Economic Justification for Solar System Sizing

It is important to realize that while the concepts of economic justification in sizing hold true throughout the country, the actual target percentages can change. For example, in Phoenix, Arizona very favorable year-round solar conditions in concert with relatively warm incoming water temperatures allow the higher design target of 82% to be cost-justifiable.

Demand Calculations and System Sizing Under the RCS Program

As the two preceding sections indicate, a significant number of complex calculations are required for the proper sizing of a solar water heater. Additionally, it is often necessary to rely on a manufacturer for performance figures of a particular product.

With these observations in mind, the Solar Energy Research Institute coordinated the development of a generalized audit procedure which allows RCS inspectors to size systems quickly and accurately working from tables. Specific tables have been generated for all RCS regions. The procedure is described in detail in the DOE Model Audit Manual and in the RCS Auditor Trainee Manual: Renewable Resource Measures. A brief overview follows:

Figure 2-28 demonstrates the RCS Model Audit for the solar hot water analysis of a typical home in Oklahoma.

In order to fill in the audit form, a number of observations must be made by the auditor at the site. Square 1 simply indicates the number of people living in the home. Square 2 indicates the daily hot water demand per person. According to simplified RCS procedure, a figure of 10 gal per person per day is used if there is not a dishwasher or clothes washing machine, 15 g/p/d if there is a dishwasher only, 20 g/p/d if there is a washing machine only, and 25 g/p/d if both appliances are present. Square 3 indicates the total load of the Oklahoma family.

The final observation needed is PSF, Square 7. PSF is the Prime Solar Fraction, a measure of the proportion of sunlight (amount of insolation) available at the potential site for collectors. The PSF is measured utilizing a solar viewing device and is computed for annual use for solar water heating. As shown above, the PSF for the Oklahoma site is 1.0 (100%), indicating that there is no shading.

① Number of Occupants	② Use (GDP)	③ Daily Load (Gallons; ①×②	④ Annual Energy Requirements (Million Btu)	⑤ SSF	⑥ Area Required (Ft^2)	⑦ PSF	⑧ Adjusted Area (Ft^2)A ⑥÷⑦
5	25	125	23.0	0.7	122	1.0	122

⑨ Local Energy Cost ($/Million Btu)	⑩ Annual Energy Cost ($) ④×⑨	⑪ First Yr $ Saved	⑫ Resident Installed Cost: 1000 + ⑧× $10/ft²	⑬ Contractor Installed Cost: 1500 + ⑧× $15/ft²	⑭ Resident Installed (Rack) Cost 1100 + ⑧× $11/ft²	⑮ Contractor Installed (Rack) Cost 1650 + ⑧× $16.5/ft²
2.66*	61.18	42.83	2220	3330		

Figure 2-28. Audit Form for Solar Domestic Hot Water

Armed with the data generated above, the auditor then turns to localized RCS tables, such as Table 2-9 for Oklahoma. Working from this Table, the auditor can immediately fill in Audit Form Square 4 (annual Btu requirement). A typical daily load of 125 gal in Oklahoma calls for 23,000,000 Btu annually.

Table 2-9. Solar Domestic Hot Water Data Table, Preferred Orientation

Preferred Orientation 0-15 Degrees from True South

RES USE	ANN USE	Collector Area Required (ft^2) for Prime Solar Fraction (PSF) = 1.0							
GPD	MIL Btu	0.2 SSF	0.3 SSF	0.4 SSF	0.5 SSF	0.6 SSF	0.7 SSF	0.8 SSF	0.9 SSF
20	4						20	26	38
30	5				17	22	29	40	56
40	7			16	22	29	39	52	75
50	9			20	27	36	49	67	93
60	11		17	24	33	43	59	81	112
70	13		20	28	38	51	69	95	130
80	15		23	32	43	58	78	104	147
90	16	16	25	37	49	65	87	122	172
100	18	18	28	41	54	72	98	133	183
110	20	19	31	45	60	80	107	149	199
120	22	21	34	49	65	88	118	160	225
130	24	23	37	53	70	95	125	175	239
140	25	25	40	57	77	103	137	187	266
150	27	26	42	61	83	109	143	201	279
160	29	28	45	64	87	117	155	212	305
170	31	30	48	68	93	123	165	230	321
180	33	32	51	72	99	129	175	239	329
190	34	33	54	76	103	137	187	250	354

STATE OK
HUD/MPS 4

Square 5 refers to SSF. SSF is Solar Savings Fraction, the proportion of water heating to be provided by the solar system. Optimum cost-effective SSFs have been provided as part of DOE's technical assistance in the RCS Model Audit. As shown in Table 2-9, the optimum solar fraction for Oklahoma is 70%.

Square 6 indicates the area of a typical collector system required to meet the SSF. Use of Table 2-9 shows that the Oklahoma site would require 122 ft^2. If the PSF (Square 7) were less than 1.0 (i.e.,some shading present), an adjusted area (Square 8) would reflect necessary system modification.

The RCS Model Audit also contains tables which allow an auditor to calculate system size in "acceptable" (15° to 45° azimuths) rather than "preferred" orientations (0° to 15° from true south). Additionally, it includes charts detailing whether or not collector racks are recommended, given a variety of site conditions.

The bottom row of entry squares in Fig. 2-28 demonstrates how the backup economic calculations are generated from the RCS audit. The key figures, of course, are the local costs of conventional energy and the installed costs of solar collectors. All localized backup is provided.

As mentioned earlier, the RCS procedures were developed to allow auditors to evaluate solar applications quickly. It must be remembered that the audits are generalized in nature, reflecting average demand, performance, and cost figures. An in-depth analysis of any particular site and any particular solar equipment may produce significantly different results.

2.3.4 System Types

Generic types of solar water heaters popular today were discussed earlier and many installation techniques are presented in the HUD Installation Guidelines (Chapter 9). The wide range of equipment and technique reflects the many approaches to solar heating. Cost, performance, and longevity are major considerations, but it must be remembered that all are modified by geography. A much more sophisticated and thermally efficient solar system will be needed to generate hot water year after year in northern Wisconsin than the type of system needed in southern Florida.

2.3.5 Interconnections

As with all solar systems, certain major conservation measures should be taken with solar water heaters. These measures can have a dramatic impact on the solar system's performance:

- Place all storage and heating tanks in heated areas.
- Insulate all hot plumbing connection lines and all water heating tanks.
- Install low-flow shower heads and faucet aerators to control demand.
- Insulate all hot water delivery lines to faucets and keep the runs as short as possible.

Following the installation, other conservation methods to be observed are:

- Maintain the lowest possible settings on the backup energy source and in the tempering valve, e.g., 120° F.

- Turn off the backup energy source whenever possible.
- Install thermometers so that homeowners can plan water usage around the availability of solar-derived heat.

The actual integration of solar water heaters into a home generally follows one of three configurations: the single-tank system, the double-tank system, or the bypass system.

The Single-Tank System

The most basic type of solar water heater is the single-tank system. This type of system is very popular in new construction since it requires the purchase of only one tank. It is also useful in older homes when the existing water heater needs to be replaced.

In this system, the same tank provides solar storage and a backup energy source, usually electricity. The solar heat is brought to the tank through an immersion coil or a separate heat exchanger. An important consideration in a single-tank with an immersed heat exchanger is that the solar energy be delivered to the bottom of the tank next to the incoming cold water (as is noted in Fig. 2-29). The backup or auxiliary electric

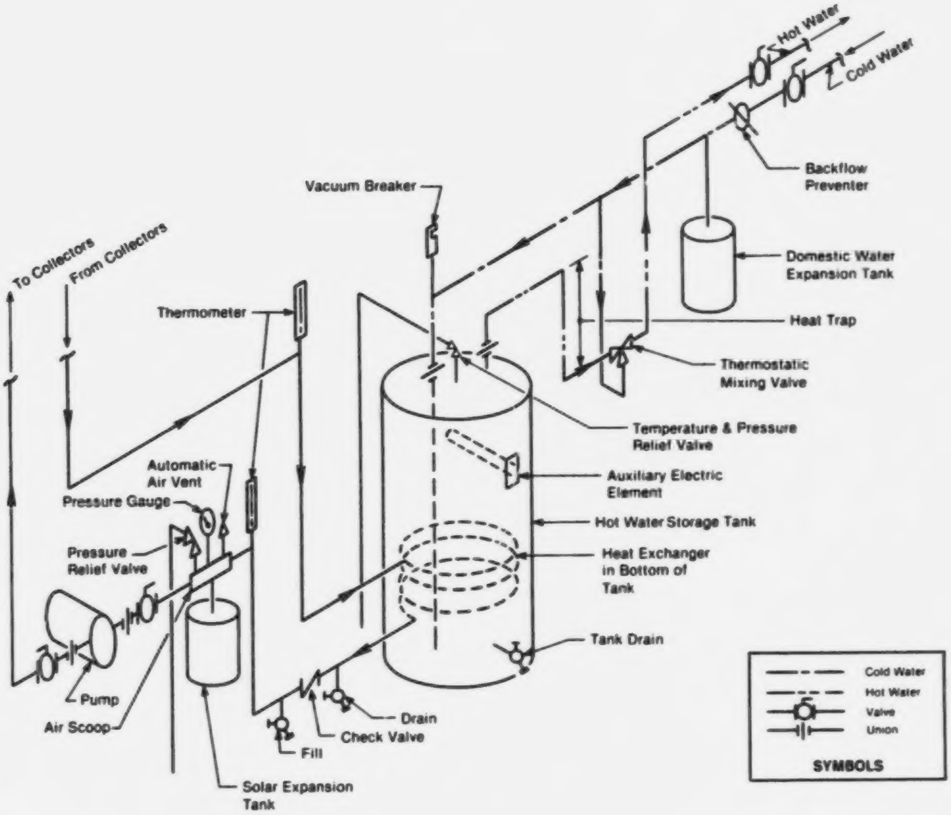

Hot Water
Cold Water
Backflow Preventer
Vacuum Breaker
Domestic Water Expansion Tank
To Collectors
From Collectors
Thermometer
Heat Trap
Thermostatic Mixing Valve
Temperature & Pressure Relief Valve
Automatic Air Vent
Auxiliary Electric Element
Pressure Gauge
Hot Water Storage Tank
Pressure Relief Valve
Heat Exchanger in Bottom of Tank
Tank Drain
Pump
Air Scoop
Drain
Check Valve
Fill
Solar Expansion Tank
Cold Water
Hot Water
Valve
Union
SYMBOLS

Figure 2-29. One Tank Closed Loop System

element should be located in the higher portion of the tank so that it will not interfere with the solar heating process. If the tank is properly constructed, the solar-derived heat will remain stratified with the hottest toward the top by natural thermosyphoning. The backup element should, therefore, only operate when the solar-heated water is not hot enough. A typical single-tank schematic follows, showing the items necessary to connect it with the conventional piping.

Since the solar storage tank does double duty as the backup heater, it must be piped into the house as if it were a conventional heater. Because it is a pressurized vessel, it must have a vacuum breaker and a mixing valve. If local code requires, a backflow preventer must be installed. When a backflow preventer is installed, many plumbers will install an expansion tank upstream to allow for significant thermal expansion of the stored water on sunny days while preventing the pressure/temperature relief valve from purging hot water.

The Double-Tank System

In the double-tank system (Fig. 2-30) the solar storage tank acts as a preheater only, placed between the home's existing terminal water heater and the cold water supply. Two such tanks in tandem would be appropriate in a case where a home already has an efficient water heater in operation. Whether oil, gas, or electric, the existing heater would supply heat only when the solar tank could not provide all of the necessary Btu to meet demand.

In certain solar system types, the two-tank configuration is necessary. An example is the drainback, in which the storage tank actually holds unpressurized heat transfer fluid rather than potable water. Two tanks also would be normal when a closed loop system has an external rather than immersed heat exchanger. In this situation a second tank is usually recommended for backup, since stratification cannot be relied on as much as when the heat exchanger is immersed in the bottom of the tank.

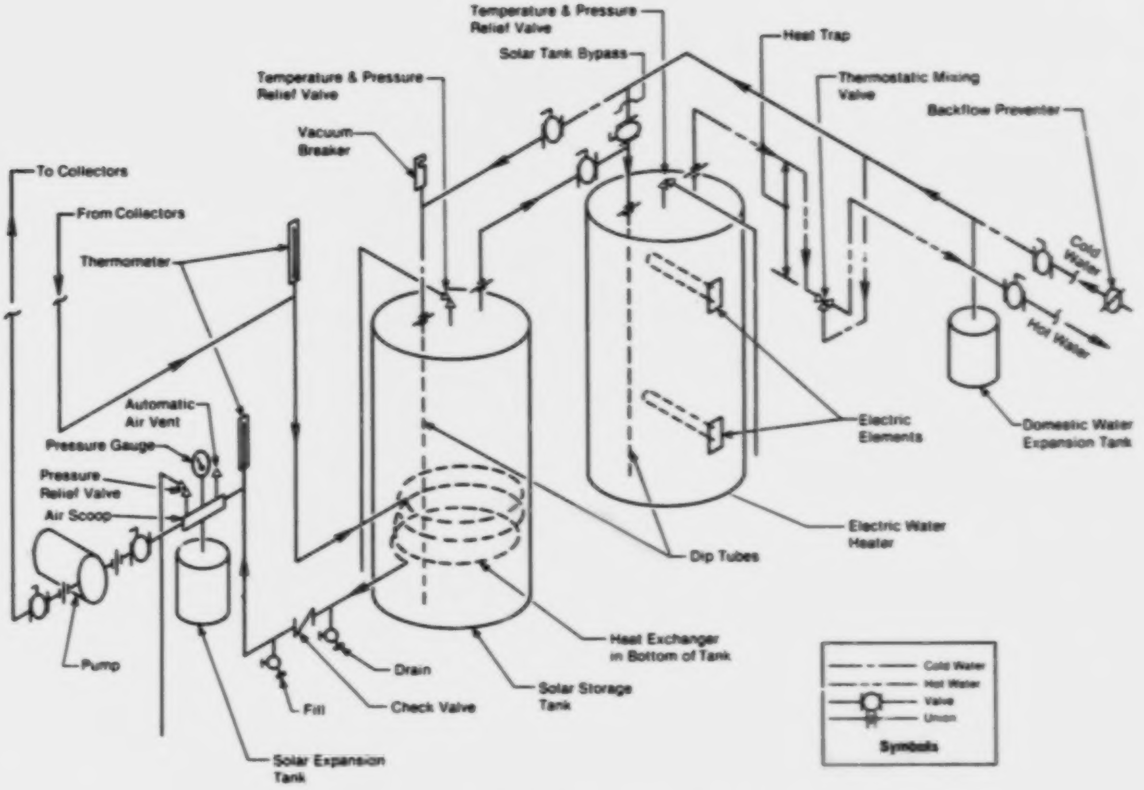

Temperature & Pressure Relief Valve
Solar Tank Bypass
Heat Trap
Thermostatic Mixing Valve
Backflow Preventer
Temperature & Pressure Relief Valve
Vacuum Breaker
To Collectors
From Collectors
Thermometer
Cold Water
Hot Water
Automatic Air Vent
Pressure Gauge
Pressure Relief Valve
Air Scoop
Electric Elements
Domestic Water Expansion Tank
Electric Water Heater
Dip Tubes
Heat Exchanger in Bottom of Tank
Pump
Drain
Fill
Check Valve
Solar Storage Tank
Solar Expansion Tank
Cold Water
Hot Water
Valve
Union
Symbols

Figure 2-30. Double-Tank Closed-Loop System (Preheater)

The interconnection of the two-tank system requires the use of all conventional plumbing components, as with the single-tank system. The vacuum breaker and the backflow preventer (if required) are both placed in line before the solar tank. The mixing valve is installed on the outlet of the second tank. Whenever storage is pressurized, both the storage tank and the backup heater should have pressure/temperature relief valves.

The Bypass System

The bypass technique (Fig. 2-31) became popular as a method of dealing with the tankless water heater, which requires a home's heating boiler to run year-round just for domestic hot water. A bypass system may be thought of as a combination of the single- and double-tank methods. It allows the home owner to use solar alone during favorable weather and to use a backup system during periods of insufficient insolation.

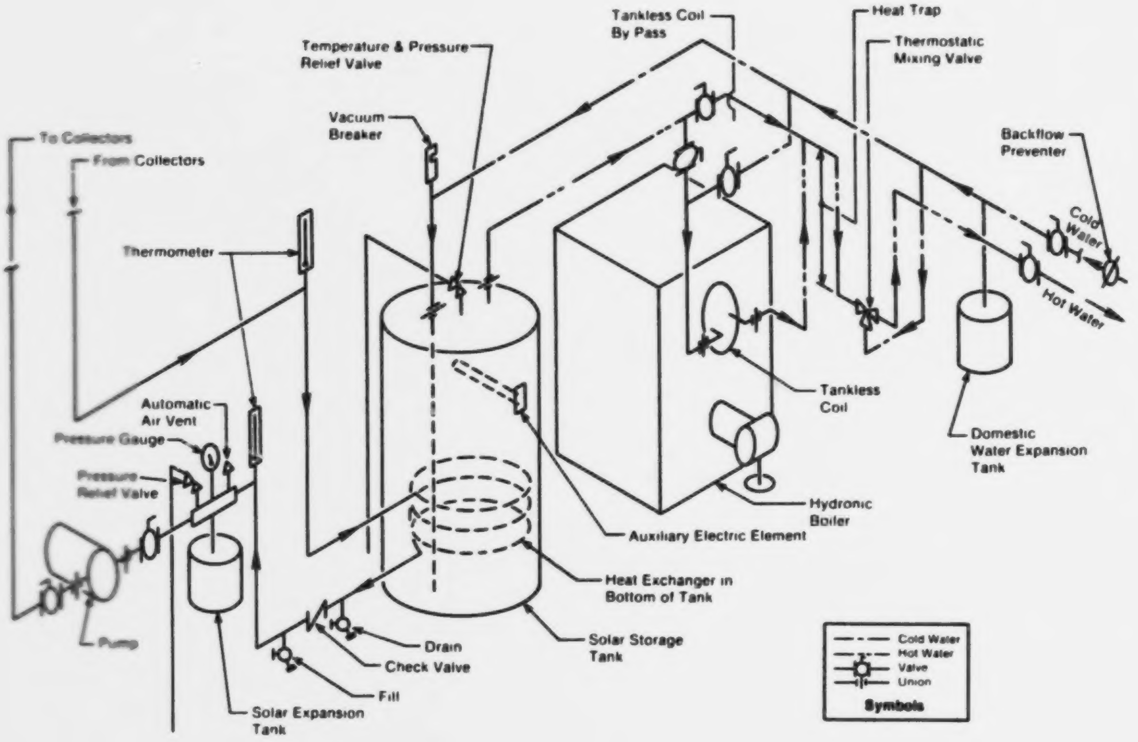

Tankless Coil By Pass
Heat Trap
Thermostatic Mixing Valve
Temperature & Pressure Relief Valve
Vacuum Breaker
Backflow Preventer
To Collectors
From Collectors
Cold Water
Hot Water
Thermometer
Automatic Air Vent
Pressure Gauge
Pressure Relief Valve
Tankless Coil
Domestic Water Expansion Tank
Hydronic Boiler
Auxiliary Electric Element
Heat Exchanger in Bottom of Tank
Pump
Drain
Check Valve
Solar Storage Tank
Fill
Solar Expansion Tank
Cold Water
Hot Water
Valve
Union
Symbols

Figure 2-31. Single-Tank Closed-Loop System with Tankless Coil

During the winter when the boiler is operating for space heat anyway and when solar conditions are less favorable, the solar tank is used in a preheat mode. During the summer months, however, when the boiler is not producing space heat, the tankless system is very inefficient. A solar bypass cuts the boiler out of its backup mode and allows the solar storage tank to function on its own, with the electric elements in the tank serving as a backup.

This same type of interconnection can be made with virtually any type of existing water heater which happens to be in a home. Whenever the backup source can be bypassed and shut off, all of its standby losses will be saved.

The storage tank in the bypass system is properly installed using the same techniques as a double-tank configuration. One point must not be overlooked, however. Regardless of whether the first or second tank is feeding hot water to the home, the delivery water must go through a mixing valve for tempering. The mixing valve must not be cut out of line in a bypass mode. During summer and in conditions of low hot water demand, many solar domestic water tanks can reach 180°F quite readily. Direct delivery of water to faucets at this temperature could scald the user. Mixing valves are, therefore, mandated by the HUD MPS (p. 6-49).

2.4 SOLAR SPACE HEATING SYSTEMS

2.4.1 Overview

At the temperatures achieved by glazed flat-plate collectors, solar energy can sometimes be used effectively for space heating of homes. Solar space heating systems, however, have not been as popular as water heating systems in new construction or retrofits for three major technical reasons.

First, an inherent challenge to solar designers is that solar energy is least available during the winter months when heating needs are greatest. Figure 2-32 compares annual space heating requirements with annual solar heat production.

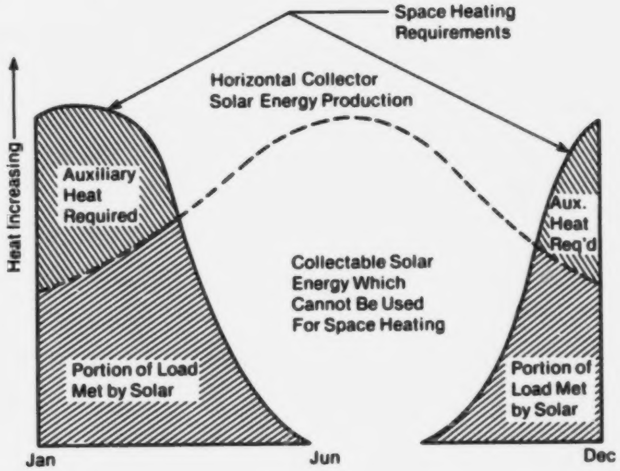


Figure 2-32. Space Heating Demand vs. Horizontal Collector Production

Because of these patterns of solar insolation, an auxiliary heater must be included to handle 100% of the heating requirements when no solar contribution is available. On the other hand, the solar system must incorporate some type of high-temperature protection for the summer months when there is abundant solar radiation but little or no demand for heat. Collectors and supporting equipment must be designed to withstand significant thermal stress.

Second, the contribution of a solar space heater is completely dependent on the thermal qualities of the home to be heated. Hot water demand, as indicated earlier, can be controlled with low-flow showerheads and aerators. Heating demand, however, is dependent on the thermal quality of the foundation, on wall and ceiling insulation, on doors and windows, and on myriad other factors. Solar space heating for homes becomes feasible only after an existing structure has been sealed and the heating load has been brought down to a manageable level.

Third, installation of a retrofitted space heating system is often complicated by the fact that not all conventional heat delivery systems are compatible with solar-assisted systems. With a solar water heater in a single-tank, double-tank, or bypass arrangement, it is possible simply to tie in to existing delivery piping to bring hot water to the faucets. With solar space heating, on the other hand, the home's ductwork, baseboard, or other delivery system may be incapable of operating effectively at the moderate temperatures produced by solar collectors in the winter months. The heat distribution system often has to be augmented or modified. These measures obviously affect the installed cost of solar, making it very difficult to justify in some existing homes.

2.4.2 Siting

Orientation and tilt angles for solar space heating systems are even more critical than with solar water heaters. Most collection for space heating occurs in winter months when the sun's path is smallest and lowest in the sky. Although orientations of up to 45° from true south are permitted under the RCS program, the preferred orientation within 15° of true south is strongly recommended.

Tilt of collectors must match the sun's shallow winter arc, and RCS therefore calls for tilt angles between latitude and latitude-plus 15°. Even steeper pitches (occasionally vertical) are sometimes used in northern parts of the country.

Shading can be an especially acute problem for winter collection because of low sun angles. Before installing any space heater, it is necessary to plot the sun's path carefully, as described in the HUD Installation Guidelines (p. 12 ff) and the Checklist Discussion within this chapter.

2.4.3 Sizing

As with solar water heating systems, the sizing of a solar space heater involves two steps: 1) calculation of the heating demand, and 2) optimization of a solar system to meet that demand. As has been stated earlier, if the home is not thermally efficient to begin with, the proposed solar investment would be better spent upgrading the home's thermal efficiency. Many solar engineers feel that systems should be considered for residences only when demand has been kept to approximately 8 Btu or less per ft^2 per degree day.

Once an accurate heat-loss calculation has been made for the home (or areas of the home in question), a collection and storage system can be designed. Goals of a 30% to 70% contribution are often cost-effective for space heating. Frequently, however, the final determinant will be the availability of roof space, as space heating typically requires a large area for collection.

Manual calculations can be made using base numbers provided by a manufacturer, but with space heating many designers prefer to use one of the large number of computer-assisted detailed sizing procedures. Perhaps the best-known method now available is the F-Chart, developed in the mid-1970's at the University of Wisconsin. The program can handle an impressive number of variables relating to site characteristics, local weather patterns, and specific collector efficiencies. Details for use of F-Chart are included in HUD MPS, (Appendix A).

Sizing Solar Space Heating Systems Under the RCS Program

As is the case with solar hot water applications (see Section 2.3), the sizing of solar space heating systems under the RCS Program is described in detail in the DOE Model Audit Manual and in the RCS Auditor Trainee Manual: Renewable Resources Measures. The intent is to allow an auditor to perform a quick analysis of technical and economic feasibility.

It should be noted that RCS space heating audits are not applicable in homes with steam heating, electric resistance heating or electric resistance baseboard heating. Further, active solar space heating is not an applicable RCS measure in a number of areas of the country.

The observations made by the auditor at the site are analagous to those made for domestic hot water. The demand, Annual Energy Requirement for Heating, is actually determined in the energy conservation section of the audit. The Prime Solar Fraction (PSF) is taken for winter months (Square 4 below). Figure 2-33 demonstrates the RCS Model Audit Form.

	① Projected Area	② Slope Compensator	③ Actual Area ①×②	④ PSF	⑤ Effective Area 3 ×④	⑥ Heur	⑦ Efficient Heur ⑧× 0.9	⑧ SSF
Active (A)	Sketch	DB/CA		Sketch		P5, L4		DB/CA
Combined (B)								
	Sketch	DB/CA		Sketch				DB/CA

	⑨ Annual Heating Cost	⑩ Annual Hot Water Cost	⑪ Total Heating Cost ⑨+⑩	⑫ First Yr $ Saved ⑧×⑪	⑬ Contractor Cost $ ___ + ③× ___/Ft²	⑭ Contractor Rack Cost $ ___ × ③× ___/Ft²
Active (A)		▨				
Combined (C)						
	P5, L4	P13, L2				

Figure 2-33. Audit Form for Solar Space Heating

The proposed mounting location for the solar panels is identified from a sketch or photograph. Next, the projected (horizontal) area, Square 1, of the south-facing roof is estimated by the length and width measurements taken during sketch preparation. The area compensator, Square 2, is taken from the Slope Comparator (Figure 2-34). Square 3, the actual area, is then calculated by multiplying Square 1 by Square 2.

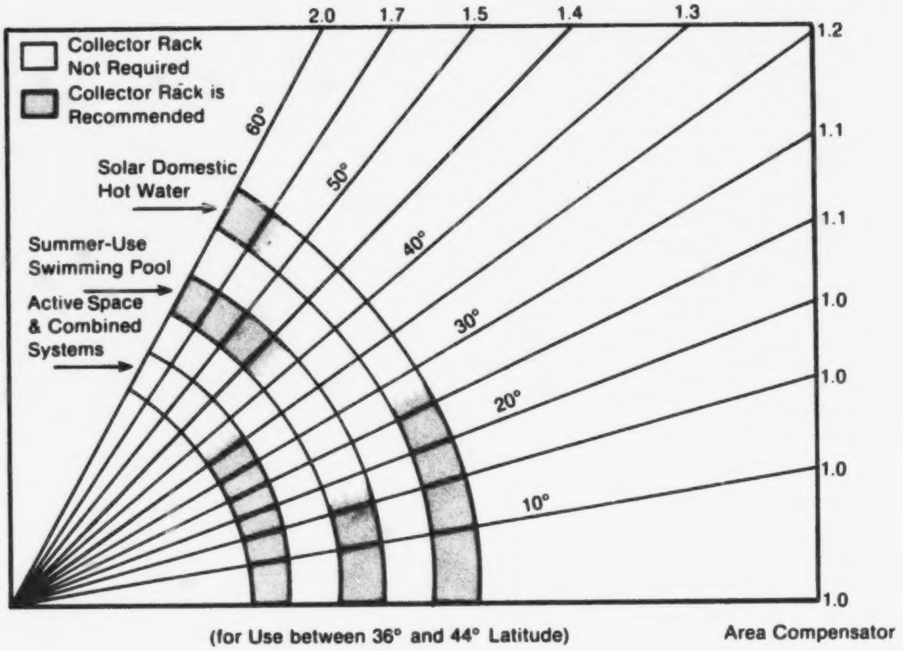

2.0
1.7
1.5
1.4
1.3
1.2
1.1
1.1
1.0
1.0
1.0
1.0
☐ Collector Rack Not Required
▨ Collector Rack is Recommended
60°
50°
40°
30°
20°
10°
Solar Domestic Hot Water
Summer-Use Swimming Pool
Active Space & Combined Systems
(for Use between 36° and 44° Latitude)
Area Compensator

Figure 2-34. Slope Comparator

The effective area for the collector, Square 4 is determined by multiplying the actual area by the PSF. The seasonal heating use rate (HEUR) is entered and multiplied by 0.9 to obtain the Efficient HEUR. The efficient HEUR is listed in the RCS Solar Space Heating Data Tables, which provide required collector areas based on Efficient HEUR for preferred or acceptable orientations, SSF, and an assumed PSF of 1.0.

As with the domestic water audit, the bottom row of squares in Figure 2-33 relate to the subsequent RCS economic evaluation of the proposed installation.

2.4.4 Interconnections of Liquid Space Heating Systems

One of the foremost considerations in the integration of a solar space heater in an existing building is the manner in which heat is drawn from solar storage. There is, of course, an economic benefit in attempting to use the delivery system already in place, be it a warm air system with ductwork or a hydronic system utilizing baseboard radiation.

The problem is that in any solar system it is necessary to make full use of all the solar-derived storage heat. In order to do this efficiently, a space heating delivery system must be able to draw storage heat down to a low temperature (perhaps 90° or 100°F) and still deliver the proper warmth to the space. As can be inferred from the section on controllers, the lower the storage temperature, the lower the collector temperature at which collection can begin. Therefore, the lower the storage temperature, the greater the efficiency of the collectors.

Many methods of delivering solar space heat from liquid systems have been used. The four most common are:

- water storage/air distribution through existing duct work
- water storage/forced hot water distribution system

- water storage/parallel forced hot water distribution
- water storage/air-to-air heat pump distribution

Water Storage/Air Distribution

If a home with forced air space heating is suited to solar and if its ductwork is properly designed, sized, and installed, a solar system can often be integrated with the entire heating system.

The water storage/air distribution type of integration (Fig. 2-35), has been popular because of its simplicity. When heat is needed, solar-derived hot water from the storage tank is circulated through a water-to-air heat exchange coil in the return-air trunk upstream of the furnace. The blower in the furnace simultaneously draws air through the return-air duct system and into the home. The burner itself will not turn on as long as the solar heat exchange coil can provide sufficient temperatures. When it cannot, the furnace will provide backup heat.

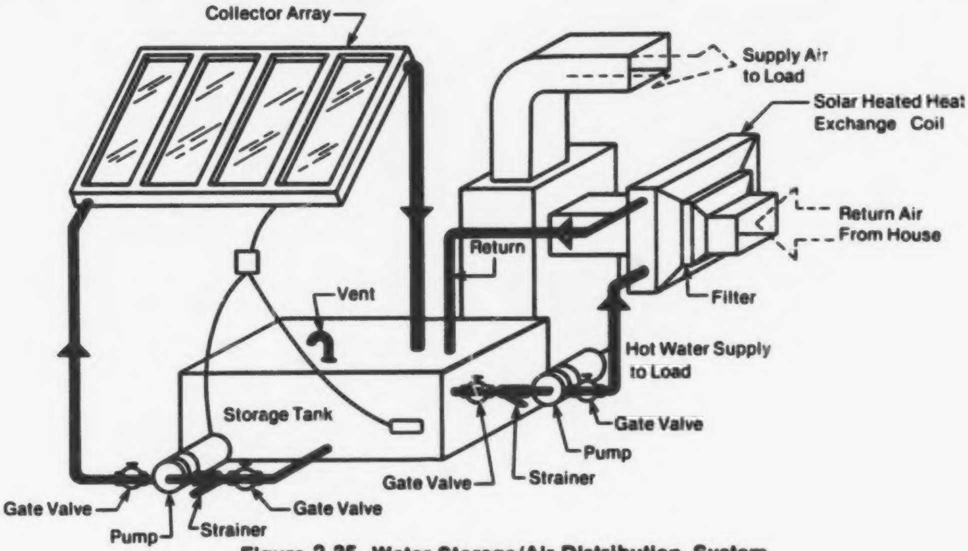

Collector Array
Supply Air to Load
Solar Heated Heat Exchange Coil
Return Air From House
Return
Filter
Vent
Hot Water Supply to Load
Storage Tank
Gate Valve
Pump
Strainer
Gate Valve
Gate Valve
Pump
Strainer
Gate Valve

Figure 2-35. Water Storage/Air Distribution System

The most common method of controlling these modes is with a two-stage thermostat. The first stage controls the solar heat alone and the second stage controls the solar and the backup heat. When the thermostat calls for heat, the first stage is activated. If it cannot handle the load, the second stage calls for the furnace to operate.

Because of the need to draw solar storage down to the lowest temperatures as efficiently as possible, a major concern in the installation of any solar system or subsystem utilizing ductwork is heat loss. A study of a residential project in Lubbock, Texas in which air delivery was used proved that normal construction technique is far from adequate for solar systems. Such a significant percentage of the solar-derived heat was lost in transport through leakage that the solar heat actually delivered was minimal. All ductwork for solar-supplied heat must be carefully insulated; all duct joints must be carefully tooled and caulked.

Water Storage/Forced Hot Water Distribution

Millions of homes in this country use an hydronic heating system. This is a central heating system which relies on a boiler to heat water which is distributed through the house in pipes. The heat is often delivered to the living space by finned-tube convectors, or baseboard radiators.

On the surface it would seem that this type of system is highly suited to solar assistance. A number of design concerns, however, make the hydronic interface one of the most difficult challenges the solar industry faces today. Most of the problems center on the fact that finned-tube convectors rely on circulation of 180°F water from the boiler in order to provide the necessary convective action to heat the space. This high temperature is difficult for flat-plate collectors to achieve consistently, especially in winter months. To compensate for the lower (and more efficient) solar temperatures, it is usually necessary to add to, perhaps even double, the amount of finned tube convectors in place. This augmentation is not always feasible in existing homes.

When proper distribution can be achieved, the solar system may be interfaced with the boiler using bypass valving, as shown in Figure 2-36. When solar storage is warm enough to handle the heating demand, water is circulated from storage directly through the baseboard, bypassing the boiler. When the solar storage is too cool to provide the necessary heat, water is circulated through the boiler and then to the baseboard, bypassing solar storage. Under severe conditions, seemingly warm water in storage may go unused for a time while the auxiliary boiler is meeting a high demand in the home. However, stored solar heat may be called upon later when the load is less severe or when storage temperature has been increased by additional solar input. If the delivery lines and storage are well-insulated, solar heat is not wasted.

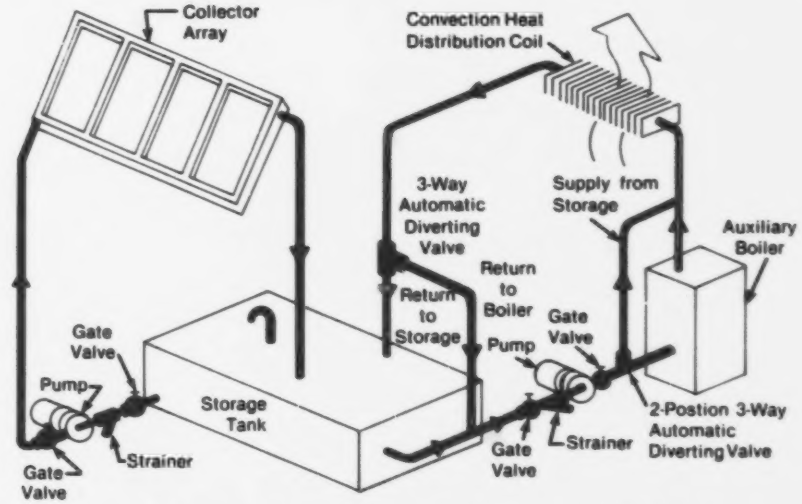

Collector Array
Convection Heat Distribution Coil
3-Way Automatic Diverting Valve
Supply from Storage
Auxiliary Boiler
Return to Boiler
Return to Storage
Gate Valve
Pump
Gate Valve
Pump
Storage Tank
Strainer
Gate Valve
Gate Valve
Strainer
2-Postion 3-Way Automatic Diverting Valve

Figure 2-36. Water Storage/Forced Hot Water System Distribution

It is not recommended that the water be circulated from the storage tank to the boiler and then to the baseboard. This configuration would not make full use of the low solar derived temperatures. In many cases, continued operation in this mode could gradually drive the solar storage temperature up. Storage capacity would then be used for auxiliary heat rather than solar, and collector efficiency would be reduced.

Homes having radiant heating systems (typically using copper tubing imbedded in concrete slabs or in the walls or ceiling) can sometimes make good use of solar (see Fig. 2-37). Maximum surface temperature for a ceiling or wall system is in the order of 125°F; for a floor panel, 85°F. These lower temperatures allow radiant systems to be more compatible with solar than finned-tube convector systems, given the nature of low-temperature solar collection and storage.

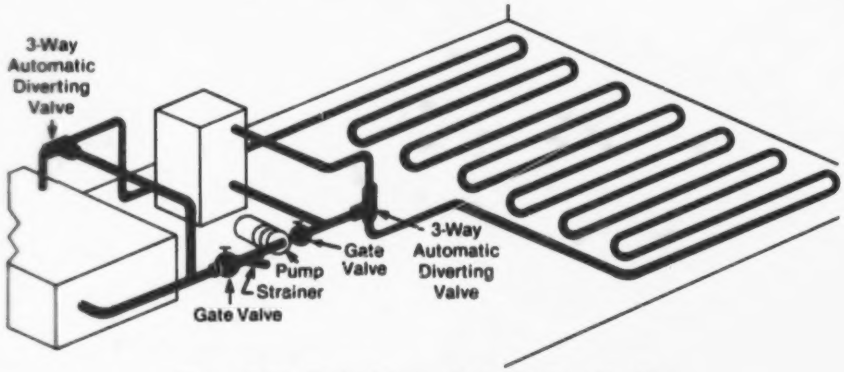

3-Way Automatic Diverting Valve
Gate Valve
Pump
Strainer
Gate Valve
3-Way Automatic Diverting Valve

Figure 2-37. Water Storage/Solar Radiant Heating

Whatever the type of hydronic heat-delivery system, the proper design and installation of control mechanisms and valving are crucial. Because of the relative complexity of the interconnections, many more field problems have been associated with hydronic than with warm air delivery of solar heat. Designers and installers are advised to consider water storage/water distribution very carefully.

Water Storage/Parallel Forced Hot Water Distribution

Water storage/parallel water distribution is a technique used more and more frequently in the retrofitting of existing homes with solar space heating (see Fig. 2-38). This technique typically identifies one specific area of the building as an appropriate space for solar heat. These are often areas of frequent use, such as kitchens and living rooms, which might need heat at times when other zones could be kept cooler. To heat this particular space, an appropriately-sized heat delivery system is installed for a stand-alone solar system. Fan-coil units are often used because of their ability to operate at moderate temperatures, their effective heat exchange characteristics, their compact size, and relative ease of installation in existing homes.

In many cases, the solar-assisted zone of the home can operate totally on heat drawn from solar storage. When more heat is needed than solar can supply, the auxiliary boiler or furnace will operate as normal. An advantage of this configuration is that lower solar temperatures can be utilized, resulting in higher collector efficiencies.

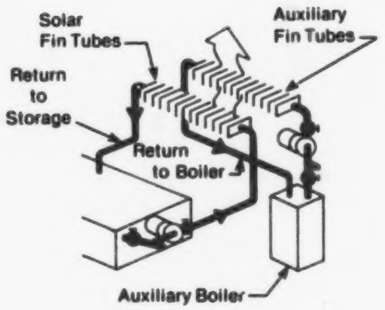

Solar
Fin Tubes
Auxiliary
Fin Tubes
Return
to
Storage
Return
to Boiler
Auxiliary Boiler

Figure 2-38. Parallel Distribution

Water Storage/Air-to-Air Heat Pump Distribution

In the water storage/air-to-air heat pump distribution system (see Fig. 2-39), normally the fan unit of the heat pump is to draw the cool return air from the house back across the solar heat exchanger. In this mode the heat pump itself would not be contributing to the heating load. However, whenever the storage temperature is not high enough to heat the air sufficiently, the heat pump begins operation.

When the storage temperature is below the space temperature, the solar energy cannot be used at all. However, if the solar system is properly sized, it can reduce significantly the operating time of the heat pump's compressor, and therefore the energy needed to power it.

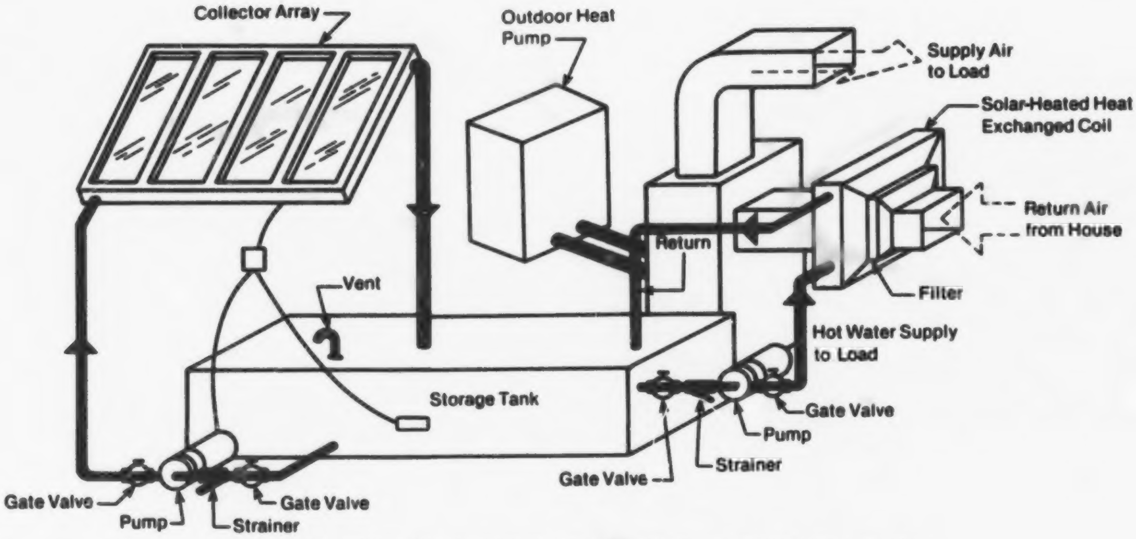

Collector Array
Outdoor Heat
Pump
Supply Air
to Load
Solar-Heated Heat
Exchanged Coil
Return Air
from House
Return
Filter
Vent
Hot Water Supply
to Load
Storage Tank
Gate Valve
Pump
Strainer
Gate Valve
Gate Valve
Pump
Strainer
Gate Valve

Figure 2-39. Water Storage/Air-to-Air Head Pump Distribution System

2.4.5 Combined Solar Space and Water Heating Systems

Regardless of the type of solar space heating used or its interconnection configuration, it is always wise to consider the inclusion of a solar water heater in the system. The year-round need for domestic water heating provides a good outlet for some of the otherwise wasted heat a space heating system can generate during the summer months. Special care must be taken to ensure that the solar storage tank is adequately insulated, so as not to add to the summer cooling load.

The typical interconnection technique is straightforward as shown in Fig. 2-40. A heat exchanger is placed either in the main storage tank or in some cases in the water heater itself. Using a controller and a pump, solar storage can provide preheated domestic water.

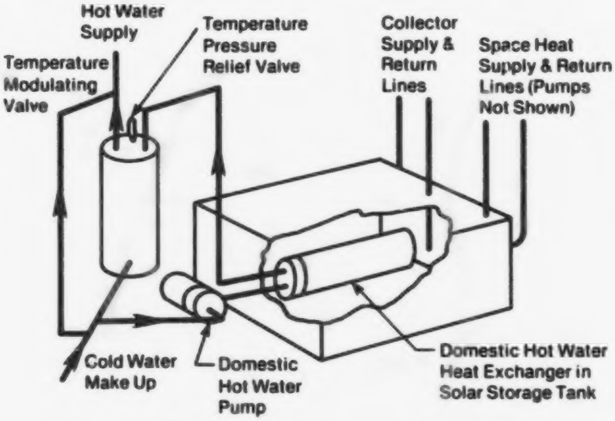

Hot Water Supply
Temperature Pressure Relief Valve
Temperature Modulating Valve
Collector Supply & Return Lines
Space Heat Supply & Return Lines (Pumps Not Shown)
Cold Water Make Up
Domestic Hot Water Pump
Domestic Hot Water Heat Exchanger in Solar Storage Tank

Figure 2-40. Combined Solar Space and Domestic Water Heating Systems

2.4.6 Solar Air Systems

Figure 2-41 details a typical solar air system interfaced with an air distribution system, backed up by a conventional furnace.

When the solar control system indicates that the discharge air stream of the collector has exceeded a predetermined set point and the house thermostat is calling for heat, the system will assume the direct operating mode. The collector fan will start up, normally-closed damper #3 will open, and circulation through the collectors will begin. In this condition, many systems will by-pass storage since rock storage is relatively slow to heat up. Normally-open damper #4 will close, and dampers #1 and #2 will open, allowing the solar heated air to flow directly into the home.

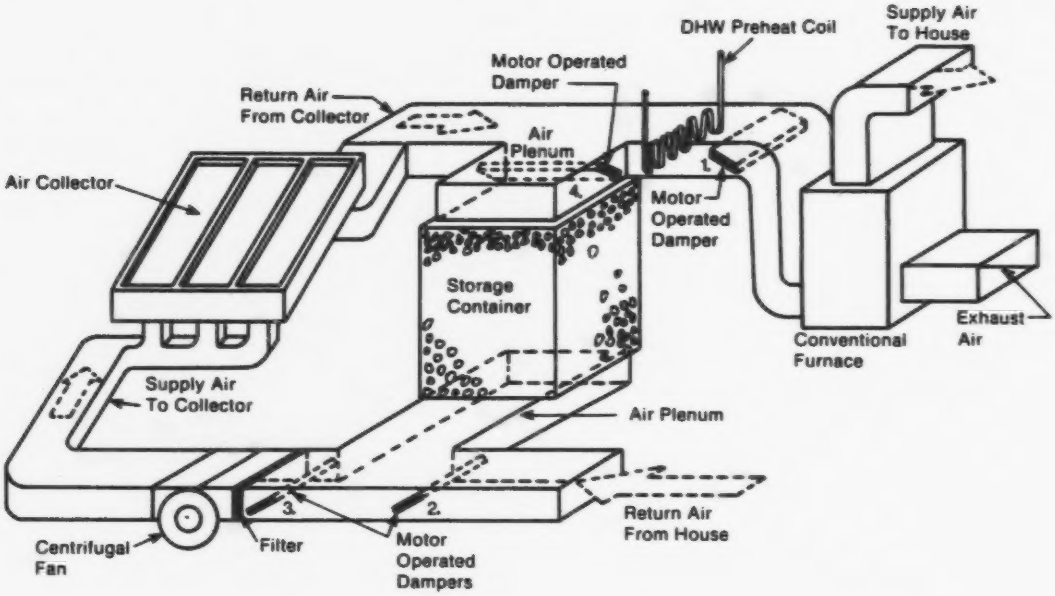

DHW Preheat Coil
Supply Air To House
Motor Operated Damper
Return Air From Collector
Air Plenum
Air Collector
4.
1.
Motor Operated Damper
Storage Container
Exhaust Air
Conventional Furnace
Supply Air To Collector
Air Plenum
3.
2.
Return Air From House
Centrifugal Fan
Filter
Motor Operated Dampers

Figure 2-41. Air System with Rock Storage and Forced Air Distribution

When the controller indicates that solar heat is available for collection but the home is not calling for heat, the system will assume the heat storage mode. Damper #3 will open and the blower (or centrifugal fan) will move air up through the collectors, down to the air plenum, and through normally open damper #4, down into storage. The heat will be allowed to stratify in distinct layers, as discussed earlier.

Conversely,when the space inside the home calls for heat but no solar collection is taking place, dampers #1 and #2 (normally closed) will open. The furnace blower will force cool air through storage, analogously to the way it would through the liquid-to-air heat exchanger typical of a water storage system. (The furnace blower will be on at all times in continuous circulation [CAC systems]). It is noteworthy that the cool air will be introduced to the bottom of storage and taken out of the top, the opposite flow direction of the solar loop.

2.5 SOLAR POOL HEATING SYSTEMS

2.5.1 Overview

Solar swimming pool heaters have enjoyed enormous popularity in this country, especially in California and Florida. Solar pool heating is far more popular than any other type of solar application. The main reasons for this widespread use are low cost, ease of installation, and almost negligible maintenance. Additionally, many homeowners are considering solar because conventionally-fueled pool heating systems have been banned by certain state or municipal ordinances.

Heating of outdoor pools differs from solar space or water heating in that demand and collection occur only in summer, since most families wish to swim only when the weather is warm and sunny. The pool water to be heated is usually cooler than the outside air during the day, eliminating the need for insulation and other methods to control heat loss from the collectors. In short, a very simple technical approach is possible.

2.5.2 Siting

Since pool collectors are usually at work only at times of high summertime sun, a wide orientation range is acceptable for pool heating. In many cases, any south-facing roof area oriented between due east and due west will be workable, given adequate collector area. A wide tolerance is also possible for tilt angles, as long as the high arc of the summer sun is remembered. Tilt angles ranging from local latitude to 15° less than latitude will work well.

Some special care does need to be given to shading, however. Summer sun can often be used earlier and later in the day than autumn, winter, and spring sun. For that reason, it is wise to ensure that the site is shade-free, if possible, from 7:00 am to 5:00 pm, extending the 9:00 am to 3:00 pm hours the HUD Installation Guidelines (p. 15) suggests for solar water heating.

2.5.3 Sizing

When the popular unglazed pool collector is utilized, certain rule-of-thumb sizing methods can often be used. One major manufacturer recommends that a minimum of 50% of the pool surface area be sized in collector area for south-facing installations. The ratio would increase to 75% of the pool area for east- or west-facing systems.

Many more specific sizing methods can be used. The method that follows, though, is typical since it involves the familiar two-step process of (1) determination of Btu demand and (2) optimization of collector area to that demand.

(1) Determine the average nighttime heat loss of the pool.

The heat losses that occur when a solar heater is not working are difficult to measure, as they are dependent on the time of year, evening temperature, wind conditions, relative humidity, etc. For many climates an estimate of 3°F loss per night can be used for early and late swimming season. To be more precise, simply compare the 6 pm and 8 am pool temperatures the following morning for a number of days and average them out.

(2) Add the nighttime heat loss + 2°F = ____.

This figure represents the number of degrees that the solar system sould raise the pool water each sunny day.

(3) Multiply the number of gallons of water in the pool by 8.33 = ____.

This equals the number of Btu to raise the pool water 1°F.

(4) Multiply Step 3 by Step 2 = ____.

This represents the number of Btu required to raise the pool water the number of degrees called for in Step 2.

(5) Divide Step 4 by 1750 (250 Btu ft^2/hour x 7 hours) = ____.*

This figure represents the number of ft^2 of collectors needed to raise the pool water the necessary number of degrees.

(6) Divide Step 5 by the number of ft^2 per collector = ____.

This will be the number of collectors needed. Most pool panels are 4 x 10, or 40 ft^2.

Sizing techniques such as the one above are designed to provide systems which will give 100% contribution in the summer and will extend the swimming season approximately one month in spring and fall. If a conventional heater is in place, it can occasionally be used for backup, as necessary.

Pool collectors can use a vast amount of roof area, however, and available space itself often becomes a sizing determinant. Sometimes optimally sized systems are not possible. For example, in many areas a 20 x 40 pool requires approximately twelve 4 x 10 ft collectors,using a sizeable 480 ft^2 roof area. A smaller system can be installed, but the lower output will be noticeable especially after cool nights in the spring and fall.

As with every other type of solar system, conservation is a critical part of pool heating. The use of a pool blanket, for example, can decrease nighttime heat losses so dramatically, that a 40% smaller solar system can often be successfully installed.

Sizing Pool Heating Systems Under the RCS Program

Although the RCS Program does provide a Model Audit procedure for solar pool heating systems, the procedure differs radically from the techniques described in the previous section. The reason for the differences is that the RCS Model Audit sizing and economics are based only on the use of the more expensive glazed collectors. It is also to be noted that the audit is applicable only when a heating system already exists,so that the solar installation would, in effect, become a "replacement" heater.

The RCS pool audit form is shown in Figure 2-42. Site observations by the auditor include Square 1, Square 2, and Square 5. The pool surface area, Square 1, is calculated by visual inspection. Squares 2 and 5, projected collector area and PSF, are calculated in the same manner as described for space heating (see Section 2.4.3).

When the effective area, Square 6, has been determined, it is compared with the largest collector area shown in the solar replacement pool-heater tables. Tables 2-10 and 2-11 represent the Pool Heating Tables for Oklahoma.

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*This is based on seven hours of available sun, with south-facing collectors. If the collectors face southeast or southwest, add 15% more area. If the collectors face east or west, add 25% more area.

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Table 2-10. Solar Pool Heating: Collector Area Required and Heat Loss

Covered Pool

Pool Area (ft^2)	Well Shielded from Wind				Moderately Shielded From Wind				Open to Wind			
	Annual Btu (x10^6)	0.3 SSF	0.4 SSF	0.5 SSF	Annual Btu (x10^6)	0.3 SSF	0.4 SSF	0.5 SSF	Annual Btu (x10^6)	0.3 SSF	0.4 SSF	0.5 SSF
300									15	16	22	27
350									17	19	25	32
400									19	22	29	36
450	Covered Pools that are either moderately or well shielded from wind would not benefit from the addition of solar collectors, due to minimal pool-heating loads during usual pool-use periods.								22	24	33	41
500									24	27	36	45
550									27	30	40	50
600									29	33	43	54
650									32	35	47	59
700									34	38	51	63
750									37	41	54	68
800									39	43	58	72

State of Oklahoma
HUD/MPS Region 4

Table 2-11. Solar Pool Heating: Collector Area Required and Heat Loss

Uncovered Pool

Pool Area (ft^2)	Well Shielded from Wind				Moderately Shielded From Wind				Open to Wind			
	Annual Btu (x10^6)	0.3 SSF	0.4 SSF	0.5 SSF	Annual Btu (x10^6)	0.3 SSF	0.4 SSF	0.5 SSF	Annual Btu (x10^6)	0.3 SSF	0.4 SSF	0.5 SSF
300	32	35	47	59	51	57	76	95	177	197	263	—
350	37	41	55	69	60	67	89	111	207	230	307	—
400	43	47	63	79	68	76	101	127	236	263	350	—
450	48	53	71	89	77	86	114	143	266	296	394	—
500	53	59	79	99	85	95	127	158	295	328	438	—
550	58	65	87	108	94	105	139	174	325	361	482	—
600	64	71	95	118	102	114	152	190	354	394	526	—
650	69	77	103	128	111	124	165	206	384	427	569	—
700	74	83	110	138	120	133	177	222	413	460	613	—
750	80	89	118	148	128	143	190	238	443	493	657	—
800	85	95	126	158	137	152	203	253	472	526	701	—

State of Oklahoma
HUD/MPS Region 4

	①	②	③	④	⑤	⑥	⑦	⑧	⑨
	Pool Area (Ft²)	Projected Collector Area (Ft²)	Slope Compensator	Actual Area ②×③	PSF	Effective Area (Ft²) ②×③×⑤	SSF	Pool Heating Load (Million Btu/yr)	Local Energy Cost $/Million Btu)
[1]									
	Sketch	Sketch	DB/CA		Sketch		DB/CA	DB/CA	

	⑩	⑪	⑫	⑬	⑭	⑮
	Pool Heating Cost $/yr ⑧×⑨	First Yr. $ Saved ⑦×⑩	Resident Installed Cost $ _____ + ④× $___/Ft²	Contractor Installed Cost $ _____ + ④× $___/Ft²	Resident Installed (Rack) Cost $ _____ + ④× $___/Ft²	Contractor Installed (Rack) Cost $ _____ + ④× $ ___/Ft²
[2]						

Figure 2-42. RCS Pool Audit Form

It is important to refer to the appropriate tables for a covered or uncovered pool and to the column which best describes wind conditions. The heading of the subcolumn whch lists an area figure smaller than, but closest to the calculated effective area is the SSF value that is used in the savings calculations. The collector area thus found in the table replaces the previous entry in Square 4. This value is in turn divided by the PSF to obtain a new value for the effective area, and that new value is used in the cost calculations. The pool heating load, Square 8, is determined by the same table, and the annual cost, Square 9, is determined by multiplying the pool-heating load by the regional cost for the type of fuel used.

As with the domestic water and space heating audit forms, the bottom row of squares of Figure 2-42 relate to RCS economic calculations. The first year savings figure is calculated by multiplying the SSF by the annual pool heating cost.

2.5.4 Types of Systems

Some solar swimming pool heaters use glazed collectors, heat exchangers, and other components typical of space heating systems. This would be particularly true in a combination application where, for example, one system would provide space heat in winter, pool heat in summer, and domestic hot water year-round.

The vast majority of residential solar pool heaters, however, employ the unglazed flat-plate collectors described earlier. These relatively inexpensive copper or thermoplastic panels provide excellent performance in warm weather.

2.5.5 Interconnection

Swimming pool heaters are piped in the same configuration used by a draindown water heater (Fig. 2-39). When the collector sensor indicates that heat is to be collected, a differential controller typically will switch the modes of two solenoid valves from normal, thereby diverting the pool water up through the collectors. The energy for circulation is provided by the pool pump itself, which, of course, continuously pumps pool water through the filter loop anyway. When a day's collecting period is over, the control will reset the solenoid valves to their normal position, and the water in the solar loop will drain back down into the pool.

One important consideration in planning a solar pool interconnection is to ensure that the existing pool pump is adequately sized to maintain a sufficiently high flow rate through the collectors. As a rule of thumb, 1/2-hp circulation pumps often found on swimming pool applications generally will not be adequate, but 3/4-hp pumps are usually sufficient for systems on 15,000 gallon pools.

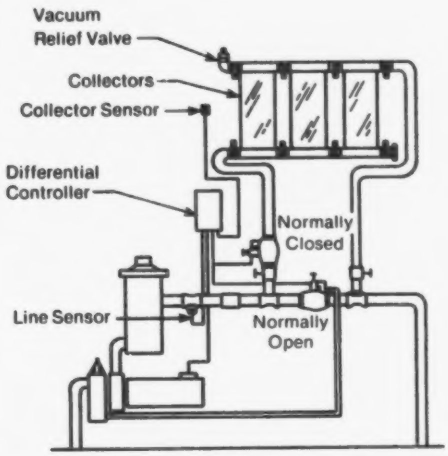

Figure 2-43. Typical Pool System Schematic

Another recurring aspect of pool heating installations is that the amount of heat needed, in concert with the nature of the unglazed collectors usually used, combine to require a relatively large area for collection. Often, sufficient south-facing roof area is not available. The leeway in orientation, however, occasionally will permit an installer to use more than one roof surface, so that collectors actually face in more than one direction. When this multi-array technique is used, installers must be careful to provide even flow rates to all collectors. In many cases, balancing valves are used in the loop to ensure adequate heat transfer.

In any case, conservation techniques must be utilized with pool heaters as with space and hot water systems. Pool heating needs can be greatly reduced in many cases by installing a wind screen around the pool. Such a barrier will control breezes blowing across the pool surface that add enormously to evaporate losses. Another increasingly popular measure is the installation of a pool blanket. These transparent covers will reduce heat loss from the pool while it is not in use. They will also allow direct solar gain. As with any outdoor solar component, however, blankets must be resistant to ultraviolet degradation.

2.6 INSPECTION POINTS AND DISCUSSIONS

The following checklists and discussions are intended to supplement the renewable resource section of the RCS Inspector's Guide* The Inspector's Guide enumerates the inspection points, provides schematic drawings illustrating the points of inspection and provides model checklists and installer assurance forms. The checklists themselves are designed to provide useful inspection procedures for solar systems. Solar businesses around the country are utilizing so many different approaches to solar applications (such as domestic water or space heating) that it is impossible to be specific about each one. Therefore, the intent of the checklists is to ensure that each RCS installation complies with basic solar, HVAC, and safety principles.

It should be noted that no part of the procedures violates the integrity of an installation. All solar loop piping, insulation, electrical subsystems, etc.,are checked visually and remain closed so the installer and manufacturer warranties will not be voided. The checklists were developed by SERI in concert with the National Association of Solar Contractors, Inc. (NASC) and were analyzed additionally by a nationwide review panel.

The following section presents background information pertaining to each inspection point, special tools that are required to conduct the inspection, detailed methods for inspection, and supplementary information such as safety cautions for the inspector. It is anticipated that this material will be useful for training RCS inspectors as well as being a source document for the RCS Installers and Inspectors, to provide needed explanation concerning the inspection procedure. This section can provide guidance for those states/utilities where the RCS Inspector will be called upon to perform a comprehensive inspection, as well as those that elect to use the Installer Assurance approach.

The reader will note that each inspection point is presented in three parts:

- Background information concerning the system feature to be inspected, the reason behind the inspection point, and potential problems that could be detected.
- Special tools required to conduct the inspection including methods for using them.
- Inspection procedures for each inspection checkpoint, without regard for who performs the inspection.

In addition, supplementary information and supplementary inspection procedures are provided for some inspection points. Supplementary information includes safety cautions for the inspector and advice that could be provided to the homeowner. Supplementary inspection procedures describe additional inspection steps that could be performed, in conjunction with the basic inspection, to enhance the inspection quality. The supplementary inspection steps are marked with an *. It is stressed these are steps beyond the minimal needed to satisfy the intent of the RCS Post Installation Inspection. Their implementation will, however, add to the assurance that the solar system as installed, is consistent with the RCS standards.

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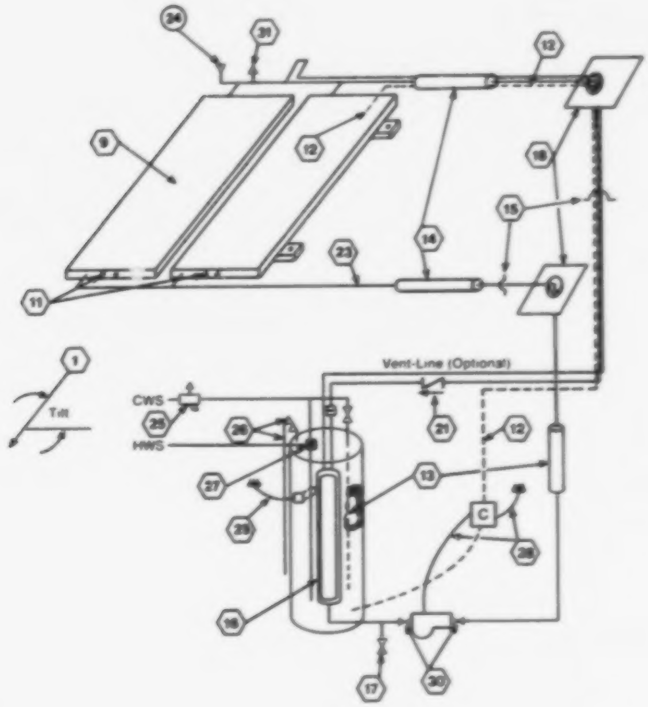
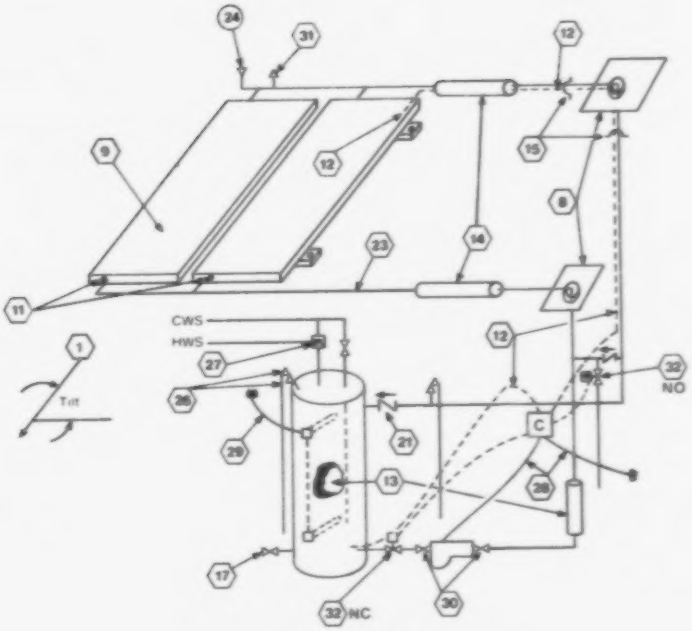
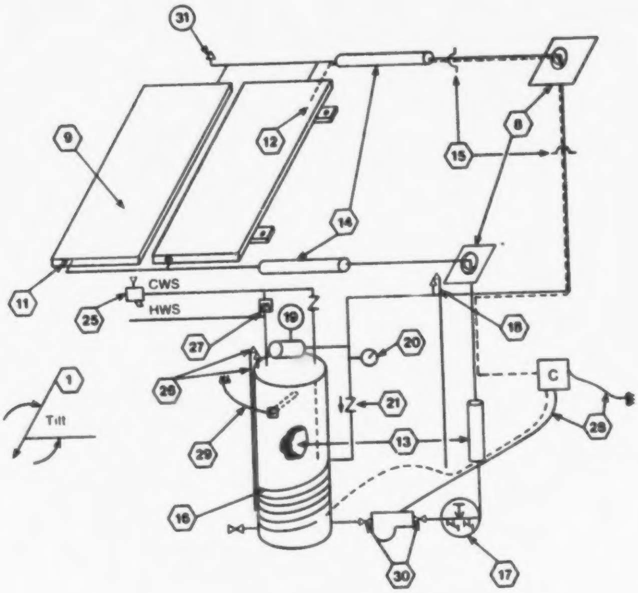
*RCS Inspector's Guide, U.S. Department of Energy, p. 75.


24
31
12
9
12
18
15
14
23
11
1
Tilt
Vent-Line (Optional)
CWS
25
26
HWS
21
12
27
13
29
C
28
19
17
30

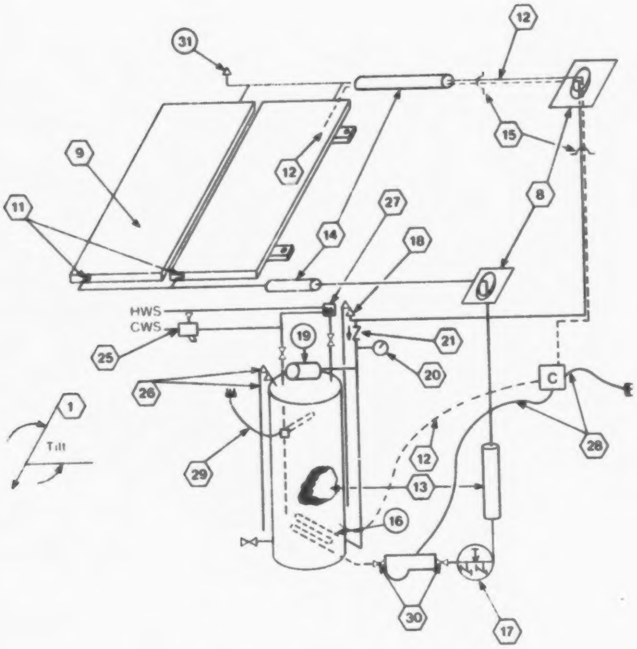
SOLAR DOMESTIC WATER HEATING SYSTEM
Drain-Back — Open Loop


24
31
12
9
12
15
8
14
23
11
CWS
HWS
1
Tilt
12
27
26
32
NO
29
21
C
13
28
17
32
NC
30

SOLAR DOMESTIC WATER HEATING SYSTEM
Single Tank — Open Loop


31
9
12
14
15
8
11
25
CWS
HWS
27
19
20
18
1
Tilt
26
21
13
C
28
29
16
30
17

SOLAR DOMESTIC WATER HEATING SYSTEM
Wrap-Around Heat Exchanger — Closed Loop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SOLAR DOMESTIC WATER HEATING SYSTEM
Tubular Heat Exchanger — Closed Loop

2.6.1 Solar Domestic Water Heating Systems (liquid only)

1. **Observe the orientation of the collectors to ensure that they face within 45° of true south. Observe the tilt angle to ensure that it is within ±10° of local latitude (see Fig. 2-44).**

Figure 2-44. Orientation and Tilt Angle

Background for Inspection

THE HUD/Installation Guidelines* advise as follows: "It is desirable to mount the collectors to catch as much of the sun's daily rays as possible. Ideally, collectors should be aimed as nearly as possible TRUE south, not magnetic south. However, variations of up to 15° east or west of south will have little effect on performance, if the system is running properly . . . It is not worth the added expense to build a special mounting frame to point collectors true south if the roof is pointed within the ±15° limits. Beyond 15°, additional calculations must be performed to determine if the expense is justified. Deviations up to 30° east or west of south will usually decrease performance by only 10%. After that, performance drops dramatically . . ."

A collector orientation east of true south will maximize solar energy capture prior to solar noon whereas an orientation west of true south will maximize solar energy capture in the afternoon.

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*Installation Guidelines for Solar DHW Systems in One- and Two-Family Dwellings, Second Edition; U.S. Department of Housing and Urban Development, U.S. Department of Energy.

Local daily or seasonal cloud cover patterns could modify the seasonal orientation guidelines. For example, coastal areas of Southern California are generally overcast until late morning during April, May,and June; consequently, collector orientation to greater than 180° would significantly improve solar collector performance during those months by maximizing daily performance in the afternoon.

The opposite would be true in locales in which cloud cover typically develops in the afternoon. Preference should then be given to collector orientation to maximize solar capture early in the day.

On collector tilt angle the HUD/Installation Guidelines advise as follows: "Collector Tilt, the angle the surface of the collector makes with the horizon, is also an important factor in system performance. Ideally, collectors should be as nearly perpendicular to the sun's hottest rays as possible . . . For a solar DHW system, a tilt equal to the local north latitude usually is considered the optimum angle. Variations either way will not seriously affect the total annual performance of the system, all other things being equal, but a greater tilt will favor winter system operations when the sun is low in the sky . . ."

Special Tools Required

- Collector orientation can be determined from either the roof or ground level using a magnetic compass, preferably the type generally used for map reading, i.e.,one employing an integral siting device such as a vertical slit or aperture.
- Collector tilt is best determined by use of an inclinometer or Abney level, preferably the type employing a fixed horizontal leg incorporating a "bubble" level. and an adjustable vertical leg which traverses an arc measured in degrees.

Inspection Procedure

- To determine the proper orientation of a collector system, it is first necessary to find true south. Because the earth's magnetic field is not directly in line with the earth's north-south axis, there are some parts of the U.S. where a "south" reading on a magnetic compass can be as much as 20° east or west of true south. The number varies throughout the country. For example, the correction for Denver is 14° E. In that area true south is actually 166° on a properly aligned compass, not 180°. In Denver, therefore, a preferred solar system orientation (± 15° of true south) would face somewhere between 151° and 181° on the compass. According to the RCS program, however, orientations between 121° and 211° are acceptable.

  There are several ways and inexpensive tools to determine true south. A local surveyor's office or a plot map in a local tax office can provide the information. Probably the most common method, however, is to take a reading on a magnetic compass and adjust this reading according to the nearest meridian line on a recent isogonic chart of the United States (see Appendix A.2). When using this method, care must be taken to ensure that the compass is not placed near ferrous metal such as automobiles, fence posts, large belt buckles, or power lines, for they will affect the compass readings. Because there are annual variations in readings, care must also be taken to ensure old isogonic charts are not being used.

- To determine the tilt angle of a collector, simply measure the angle of the glazing from the horizontal, using inclinometer, Abney level,or other suitable sizing device. For optimum year-round performance, this angle should be ± 10° of local latitude for solar domestic water heating systems. Refer to Appendix A.3 of this workbook. On March 21 and September 21, the sun at noon will be perfectly perpendicular to south-facing solar panels placed at a tilt angle of local latitude. Therefore, slopes greater than latitude would favor wintertime performance, while shallow slopes would favor summer months.

2. **Observe the sun's path relative to the collectors to ensure that the collection area will be minimally, if at all, shaded between 9:00 a.m. and 3:00 p.m. year round (see Fig. 2-45).**

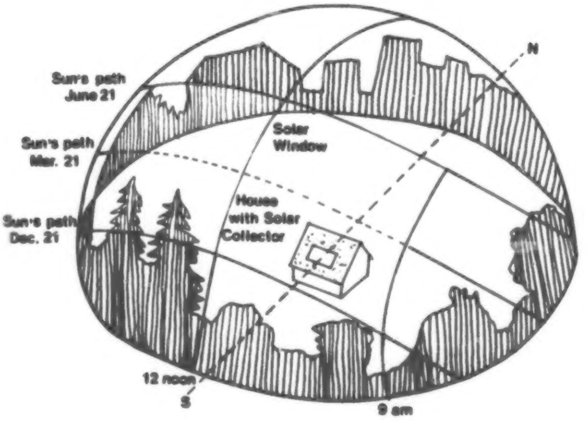

Figure 2-45. Solar Window

Background for Inspection

One of the major sources of shading is trees, so the installer and inspector should be aware of the effect of future growth. Chimneys, dormers, other buildings, new construction, and even fences may shade the collector array, especially in the winter when sun angles are low and shadows are long. By knowing the altitude (angle of sun above horizon) and the azimuth (angle between true south and point on horizon below sun) of the sun throughout the year, the installer/inspector can accurately determine if the collector array will have shading problems. However, since shading problems will affect the performance of solar energy systems the extent of an obstruction to solar radiation must be determined. This quantification of an obstruction makes it possible to adjust performance estimates, thereby resulting in cost and savings estimates that are more accurate.

Special Tools Required

Several simple field instruments called solar viewing devices are currently available and will do the job required (see Appendix A.4). The manufacturers of these devices have done all of the complicated calculations in developing the devices, which if properly used, can accurately quantify the extent of obstructions to solar radiation. As a result, a determination can be made about the size of collector needed to obtain a certain energy delivery level, or in the case of the inspector, an estimation of the reduced energy delivery if the collector size has not been adjusted accordingly. Note, however, that it is important to purchase a viewing device designed for the specific local latitude in which it will be used.

Inspection Procedure

Procedures for using a solar viewing device will vary with each type of device. It is recommended the inspector follow closely the operating instructions provided by the manufacturer of the viewing device. Several measurements should be made to ensure accuracy.

3. **Inspect the standoff between the collectors and the roof to ensure that there is a minimum of 1-1/2 in. clearance. (Local codes could dictate a greater or lesser clearance.) If the collectors are mounted directly on the roof surface, check to ensure that proper flashing has been used to prevent leakage, mildew, and ice buildup. Adequate clearance from any combustible material must also be provided (see Fig. 2-46).**

Background for Inspection

Clearance between collector and roof is necessary for ventilation to preclude moisture damage to roof and/or collector and to avoid rotting of wood shingles, growth of fungus, mold, etc. It is also needed to allow occasional removal of accumulated debris, such as windblown leaves, paper, and dirt which could trap water and subsequently swell during freeze thereby damaging roof and/or collectors.

The HUD/Installation Guidelines advise: "On retrofit installations, collectors should be raised at least 1-1/2 in. above the roof to avoid damage to shingles. Without that space, moisture buildup could cause growth of fungus, mold, and mildew. Ice dams could also form and draw water under shingles by capillary action. These factors contribute to roof surface deterioration."

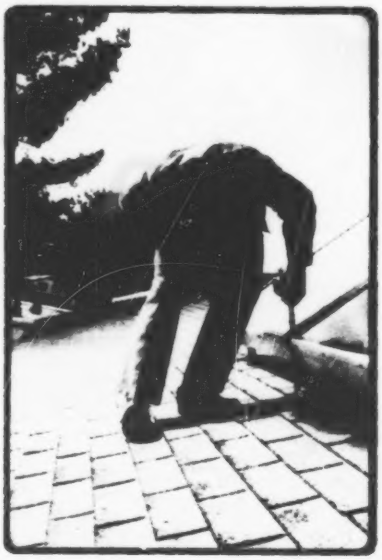

Figure 2-46. Collector to Roof Standoff

The HUD/MPS comments as follows (Section S-515-2.1): "When collectors are mounted over a roofing membrane, consideration should be given to the growth of fungus, mold, and mildew between the roofing membrane and the collector and to potential problems in re-roofing under collectors. Also, it is possible, due to extreme temperature differentials, to cause the formation of ice dams which could back water under shingles or other roofing materials causing rapid deterioration. Consideration should be given to the methods of applying non-integral collectors to roof structures and to the choice of water-proofing membrane."

Collectors manufactured to meet the "Uniform Solar Energy Code" (USEC),* and tested in accordance with ASHRAE 93-77,** will incorporate insulated back and side panels. During extended thermal stagnation, the absorber can reach 375°F for non-selective surfaces and as high as 450°F for highly selective surfaces, for short periods of time (1 to 2 hours per day). The insulated back panel and side panels should limit the exterior collector surface temperature to 250°F or less; therefore, a clearance of 1-1/2 in. between the back panel and the roof should provide adequate clearance, allowing for slight irregularities in the back panel and/or roof surface.

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*Uniform Solar Energy Code, International Association of Plumbing and Mechanical Officials; 1979 Edition.

**ASHRAE Standard 93-77, "Methods of Testing Solar Collectors Based on Thermal Performance," American Society of Heating, Refrigeration and Air Conditioning Engineers.

Ventilation is also necessary to preclude thermal damage to roof and/or collectors during extended stagnation periods. This will prevent or reduce shrinkage of wood shingles with consequential cracking; softening of composition shingles and built up roofing with consequential blistering; stretch and sagging; fire hazard to roof materials in proximity of high temperature collector components; fire hazard of accumulated debris between roof and collector, e.g., leaves, paper, pine needles.

Special Tools Required

A measuring tape or rule is sufficient to conduct this inspection.

Inspection Procedure

Using the measuring tape be sure to take measurements from the point of the collector nearest the roof.

Caution:

- Gain safe access to the roof. Do not attempt to do so if weather conditions are not favorable, e.g., high winds, rain, ice, snow.
- Be aware of site hazards such as power lines and TV antennas.
- Observe safety rules in raising, placing and stabilizing ladders.
- Wear appropriate shoes, e.g., nonslip soles.
- Be cautious not to damage asphalt shingles which can become extremely brittle in cold weather and very soft in hot weather.

4. **Inspect the collector rack, if any, to insure that it is structurally sound, weather resistant, and that compatible materials have been used (see Fig. 2-47).**

Figure 2-47. Collector Rack

Background for Inspection

When the tilt or orientation of the collector array corrects for the angle of the roof with the use of a rack, precautions must be taken to ensure that the rack is sufficiently strong and durable.

While both metal and wood racks are used, the metal racks are preferred because they will last at least as long as the collectors and require little or no maintenance.

Wood racks are less desirable because they are frequently poorly fabricated; tend to warp and twist with changes in ambient temperature and/or moisture, which can impose significant stresses within the collector container and glazing, and the exposed piping and insulation; and require frequent painting to prevent rapid deterioration unless constructed of "select redwood" or chemically treated wood.

It is critical that all mounting materials, whether used for simple standoffs or complicated racks, be fabricated from compatible materials. If dissimilar materials are used, such as steel bolts next to aluminum collector flanges, galvanic corrosion can occur. Accelerated by exposure to the elements, such corrosion can weaken the assembly very quickly, and its structural integrity can be dangerously impaired.

Most conscientious solar installers now follow a simple rule of always using one material, typically aluminum. Often manufacturers themselves provide complete, compatible mounting kits. If another metal must be utilized, stainless steel is acceptable, as it will not react with materials such as aluminum. Otherwise, the procedures below from the HUD Installation Guidelines are to be followed.

Concerning corrosion protection the HUD/Installation Guidelines advise:

"Both roof-mounted and ground-mounted collector arrays and mounting hardware (bolts, screws, washers, angles) must be carefully protected from corrosion . . .. Cadmium-plated or hot-dipped galvanized bolts can be used to mount collectors on racks. If the coating is scratched, it should be primed with zinc chromate paint or special zinc-rich coating. The exposed edges of galvanized steel angle iron should be similarly treated.

Dissimilar metals can be separated by washers made of fluorocarbon polymer (such as Teflon^{R}), phenolic (such as Bakelite^{R}), or neoprene rubber. When a bolt passes through two dissimilar metals, the inert washer should have an insulating sleeve . . .. Most collector manufacturers supply mounting hardware specifically designed for their equipment. Follow instructions carefully, and be sure to cover all holes and mounting assemblies with a high-quality sealant."

Special Tools Required

No special tools are required for this inspection. The inspector should physically put stress on all connections of the rack being careful to check for any weak areas. Care must be taken, however, not to disturb the solar loop piping, the insulation, or the sensor system.

Inspection Procedure

Review pertinent drawings and/or literature from collector manufacturer for recommended rack anchorage of collector. In general, all bolts and screws should be tight and of a material compatible with the collector.

Look for evidence of overtightening of bolts and screws, such as deformed screw heads, extruded washers, or excessive deformation of collector attachment to the rack and curb. These signs could indicate improper alignment of components and a resultant high stress concentration.

5. **Inspect the attachment of the rack or the individual collector standoffs to the roof to ensure that blocking, spanner mounting, or direct lagging into rafters has been used and has not caused leaks (see Figs. 2-48, 2-49).**

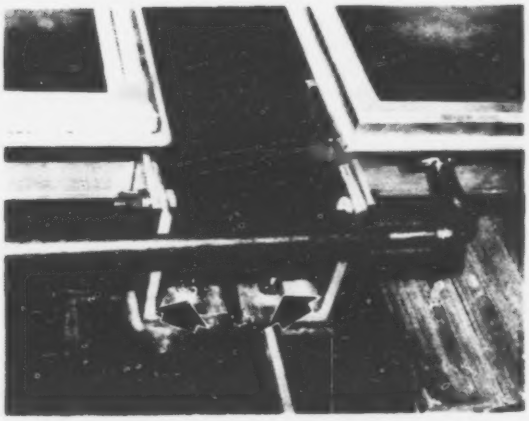

Figure 2-48. Collector Mounting Bolts

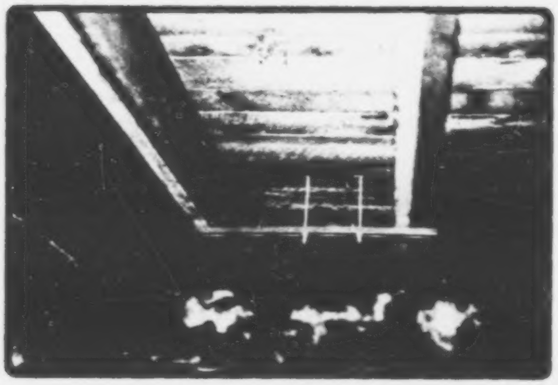

Figure 2-49. Collector Mounting Bolts (Bottomside)

Background for Inspection

A structurally sound collector rack is useless if not properly attached to the building. Uplift forces from winds, snow, and seismic loads can generate considerable loads on the points of anchorage. Three types of mounting are considered acceptable: spanner mounting, direct lag mounting, and blocking. Spanner and lag mounting are fully discussed in pp. 25-27 of the HUD Installation Guidelines. If site conditions prevent the use of these two methods, blocking can be used. In this case a block (usually a 2 x 6) is cut to fit tightly in each rafter bay where the roof will be penetrated. The block is then carefully toed into the rafters with sufficiently strong nails. The lag screws or thread rod are then brought through the sheathing and through the blocking. Lagging directly into sheathing alone is dangerous and cannot be considered acceptable.

All bolt penetrations through the roof should be covered with appropriate sealant; e.g., asphalt caulking for asphalt shingles and built-up roofing; silicone or butyl rubber sealants for wood shake, metal,and tile roofs.

Special Tools Required

No special tools are required for this inspection.

Inspection Procedure

The inspector should view the attachment of the rack or the individual collector standoffs to the roof from the underside whenever possible. This usually involves a single trip into the attic for roof mounted collectors. While in the attic the inspector should attempt to conduct as many inspection checkpoints as possible, such as examining pipe hanging (checkpoint #15) and, if possible, checking for leaks around all roof penetrations.*

6. **Ensure that any additional wind, snow, or seismic loading of the collectors comply with local codes.**

Background for Inspection

Since most solar collectors cover large areas (usually 20 ft^2) their typical dead weight (75-120 lb) generally does not cause structural problems with well-designed and well-built homes. However, collectors can contribute significantly to wind, snow, and seismic loadings. This situation is particularly acute in cases where the collectors are racked sharply off the roof surface often allowing tremendous uplift forces. In areas of significant snow fall, cavities behind collectors can fill with wet snow and result in greatly increased snow loading (pp. 22-23, HUD, Installation Guidelines).

Special Tools Required

No special tools are required to conduct this inspection. However, the inspector should have knowledge of, or access to, any local or other type code by which the system may be regulated.

Inspection Procedure

Installers and inspectors must check local codes. If there is any possibility that the increased loading cannot be accommodated, the rafters beneath the collectors can be doubled up for additional support, or a truss can be built, distributing the extra load down to bearing walls.

7. **Ensure that any home entrances are protected from snow slides in areas with snow loads of 20 lb/ft^2. In areas where snow loads are greater than 20 lb/ft^2 (check with local codes), the placement of collectors directly over entrances should be avoided. However, if there is no option, a strong deflector should be attached in a structurally sound manner.**

Background for Inspection

Snow slides off steeply pitched collectors can be sudden and dangerous if sufficient precautions are not taken (HUD MPS S-304-3). In areas where snow loads are greater than 20 lb/ft^2, it is wise to avoid placing collectors directly over entrances. If there is no option, a strong deflector should be used.

Special Tools Required

No special tools are required to conduct this inspection. The inspector should check with local codes to determine snow loads.

Inspection Procedure

After determining snow loads for the local area, a visual inspection of potential collector-related snow slide areas is sufficient.

8. **Inspect the roof for flashing anchorage, caulking, and replacement roofing to ensure that all penetrations are watertight. Inspect for a flexible and watertight seal on the solar loop penetrations (see Figs. 2-50, 2-51).**

Figure 2-50. Roof Inspection

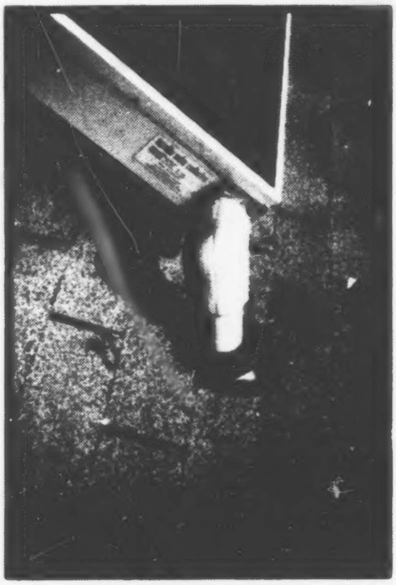

Figure 2-51. Roofing Seal on Solar Loop Penetration

Background for Inspection

Solar collectors are frequently placed under extremely rigorous climatic conditions. They are often subject to intense heat during the day and extreme cold at night. They are also subject to constant thermal expansion and contraction. For this reason, all roof penetrations must be made with the utmost care to prevent leaks and seepage, especially over time. The most popular form of penetration for the loop piping is the standard no-caulk roof shoe, (pp. 31-32, HUD Installation Guidelines). All flanges must be flexible and must fit tightly over the pipe or the insulation. As with all materials used on the roof, the flange must be able to resist degradation by ultraviolet light.

Requirements posed in the HUD/MPS (Section S-515-2.1.4) include: "Flashing systems shall be designed to permit minor repairs without disturbing the roof membrane, collector supports, or collector panels."

Flashing collars are commonly galvanized steel, aluminum and plastic.

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedure

A good way to check the seal of any roof penetration is to inspect for signs of moisture around the underside of the hole in the attic (see inspection point 5):

- Observe roof penetration from underside for adequate clearance between pipe, pipe insulation,and subroofing.
- Observe roof penetration from topside to verify proper flashing installation.
- Note any indication of misalignment of piping between flashing collar and collector, such as bowing or arching of pipe, which would impose distorting loads on the flashing.
- Inspect flashing for any evidence of warp, tilt, uplift or buckling - all indicative of improper installation and/or excessive misalignment of piping and flashing collar.

9. **Insure that collectors are safety-glazed or otherwise protected in ground or wall mounts with glazings less than 45° and those within 6 ft of the ground.**

Background for Inspection

HUD MPS (S-515-2.2.1.2.b) calls for safety glazings of shallow-pitched collectors near the ground. Most collector manufacturers who use glass prefer low-iron, tempered glass. If there is any question about the strength of the glazing, it may be covered with a layer of chicken wire one foot away from the surface. This treatment has minimal effect on performance.

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedure

Check with the manufacturer to determine the type of glazing used if a label is not attached to the glazing or collector.

10. **Verify that the collectors have been tested according to ASHRAE 93-77. A label may be attached to the collectors containing this information. If not, the model name and/or model number on the collectors will help in a verification investigation (see Fig. 2-52).**

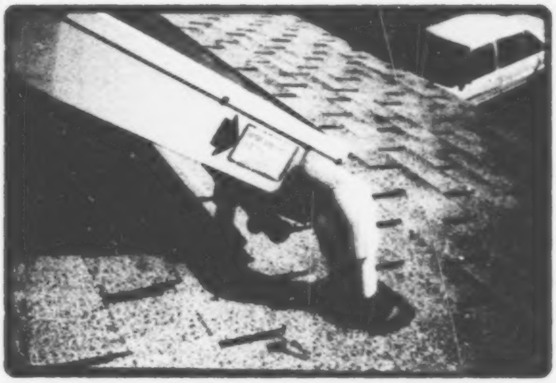

Figure 2-52. Testing Certification Label

Background for Inspection

The HUD/MPS requires manufactured solar collectors to be tested as described in ASHRAE Standard 93-77 "Methods of Testing to Determine the Thermal Performance of Solar Collectors." It is important to note the ASHRAE Standard 93-77 is a test procedure and not a minimum performance specification or quality standard.

The ASHRAE Standard 93-77 test consists of:

- Three days of preconditioning by exposure to the sun while in a dry condition, i.e., drained of any liquid.
- Instrumented testing of the collector performance for short periods while exposed to actual or simulated sunshine.
- Presentation of test data in both tabular form and as a graph (i.e., curve).

HUD/MPS imposes as an additional requirement that the ASHRAE 93-77 test procedure be repeated on the same "dry" collector after 30 days of exposure to sunshine and elements including rainfall. Comparison of thermal performance data on the initial test with thermal performance data after the 30-day exposure test must agree within 10%. In addition, no degradation of collector materials, particularly the glazing and absorber, can be evident.

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedure

- Obtain and review copy of collector testing in conformance to test procedure ASHRAE 93-77, and retest per HUD/MPS after 30 days exposure.
- Inspect collector labeling to ensure that the collectors actually installed (i.e., manufacturer, model designation) are the same as referenced in test reports.
- Visually inspect collector for evidence of glazing and/or absorber damage such as: glazing cracked, "filmed over", absorber buckled, coating flaked, or peeling.

*An abstract of the ASHRAE 93-77 testing methods can be found in Appendix A.5.

11. **Ensure that the collectors are undamaged and placed for proper flow and drainage. Weep holes must face the bottom (see Fig. 2-53).**

Figure 2-53. Drainage Weep Holes

Background for Inspection

It is important that collectors remain weather-tight. Damage to any of the seams, allowing cold air and rain or snow to penetrate, can dramatically decrease the performance of the panel. For example, abnormal amounts of water inside a collector over time can cause premature degradation of the insulation and greater heat loss.

The HUD MPS (S-615-10.5) and the HUD Installation Guidelines, (p. 23) call for collectors to be drainable. This consideration is obvious for draindown and drainback systems, but it is important for antifreeze systems as well. Many nontoxic antifreeze heat transfer fluids being used today cannot be considered permanent. In particular they can be negatively affected by stagnation conditions, which sometimes cause a chemical breakdown resulting in a change in the pH of the fluid. If these fluids become acidic or alkaline, they must be drained out completely and replaced to ensure the long life of the system.

Certain collectors, especially those with external manifolding, have a built-in slope in the manifolds themselves. If this is not the case, it is wise to ensure that the collectors are sloped upwards at the rate of at least 1/8 in./ft. This will afford proper drainage even in a closed-loop antifreeze system.

Most solar collectors on the market today have small weep holes in the casings to allow the natural condensation that often occurs on the inner side of the glazing to escape from the collectors. The collector must always be positioned so that these weep holes are on the bottom. Weep holes in the sides and top would allow the entry or rain water and would serve no function for dissipating condensation.

Special Tools Required

A measuring tape or level is usually adequate for checking proper flow and drainage by taking measurements to determine manifold pitching. A pencil, pen, or other thin rigid tool, can often be used to inspect for blockage of weep holes.

Inspection Procedure

To ensure that collectors are undamaged, a careful visual inspection is required. Mistreatment will usually show in a dented case, poorly aligned manifold headers, cracked glazing, cracked or dislodgged gasketing, and/or signs of excessive internal moisture (especially condensation).

The inspector should use the available diagnostic tools mentioned above to ensure proper pipe pitching and drainage. Inserting a pen or pencil point into the weep holes will usually be sufficient to remove any materials that may have settled in weep holes.

12. **Inspect for weather protection of all outdoor sensors, sensor wire, and wire splices. Ensure that sensors are not mounted on the outside of the case or on the roof (see Fig. 2-54).**

Figure 2-54. Weather-Protected Sensor (small dot inside glazing)

Background for Inspection

A typical system for control of a solar DHW system includes:

- an electronic temperature sensor fastened to the solar absorber of one collector or strapped to the pipe exiting the collector
- another electronic temperature sensor attached to the bottom third of the storage tank or DHW tank, or in a well installed near the bottom of the tank during manufacture
- an electronic controller, which compares, in effect, the temperature difference between the collector temperature sensor and the stored water temperature sensor

On potable water collector systems, if the collector sensor indicates a potential freeze condition, the controller switches drainage valves to open, i.e., drains down the collector and piping to preclude freezing. Another possibility is for the controller to switch on the pump to circulate water from storage to the collectors to prevent freezing.

In order to be extremely reliable and accurate, the sensors and controller must be protected from the cumulative effects of dirt, wind, rain, ice, snow, and sun. Protection from the damaging elements is most economically accomplished by installing the wiring between the pipe insulation and jacket (plastic or metal) where it is isolated and protected from both the elements and the heat from the circulated fluid. All sensor wiring attached to pipes should be insulated and weathertight to prevent intrusion of water or dirt.

Sensors must not be mounted on the outside of the case or on the roof, as proper temperature readings reflecting the "greenhouse effect" of the absorber and the cover glass would be impossible.

Sensors on or near the storage tank should be securely attached to the tank wall (epoxy glue typical), or inserted in well on tank wall, or strapped to pipe near tank wall.

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedure

Visual inspection of all sensors, sensor wires, and wire splices is recommended. In some cases the absence of visible sensor wires and sensor wire splices can be a desirable indication of insulated protection, provided the wires or splices are actually under the pipe insulation.

13. Inspect all pipe insulation for a minimum R-value of 4. All piping over 1 in. should be insulated to R-6. Storage tanks must be insulated to R-11 (see Fig. 2-55).

Figure 2-55. Pipe Insulation

Background for Inspection

The HUD Installation Guidelines (pp. 46-49) call for a minimum of R-4 on normal solar hot water system piping (R-6 for piping over 1 in.). Table 2 1 breaks out the R-value per inch of the standard pipe insulating materials available today.

Table 2-1. Thermal Value Per Inch of Typical Solar Pipe Insulating Materials

Type	R Value
Elastomer	3.5
Fiberglass	4.0
Phenolic Foam	4.3
Urethane	7.0

Storage tanks are required to be insulated to R-11. In almost all cases, this requires the addition of extra "onsite" insulation to what manufacturers supply in typical storage tanks. The most common type of onsite insulation is fiberglass. Table 2-2 can be used to compute total R-value of fiberglass storage tank insulation.

Table 2-2. Thermal Value of Fiberglass Storage Tank Insulation (Source: Northeast Solar Energy Center)

Thickness in Inches	R Value
1/2	1.6
1	3.2
1 1/2	4.8
2	6.4
2 1/2	8.0
3	9.6
3 1/2	11.2
4	12.8
4 1/2	14.4
5	16.0

The entire solar system should be insulated per the RCS standard with the exception of the following: pump motor housings, tempering valves, top of air vents, openings in vacuum breakers and relief valves.

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedures

Verify that insulation R-value, or maximum heat loss per exposed lineal foot, is adequate with respect to the above-mentioned guidelines, or per local code whichever is greater. Also inspect exposed pipe and insulation for proper assembly, particularly at pipe bends and at the juncture of flexible pipe connections to the solar collectors.

14. **Inspect outside insulation for waterseal and for ultraviolet inhibition. Rigid pipe insulation should be wrapped with weather-protective material. Elastomer insulation must be painted with a flexible finish or wrapped to prevent ultraviolet degradation (see Fig. 2-56).**

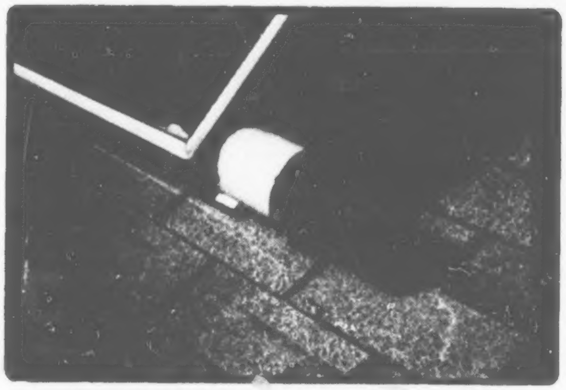

Figure 2-56. Weather-Protected Insulation

Background for Inspection

An important part of any active solar system inspection is to check that all outside insulation is carefully and completely weather-sealed. A hole or a separation in outside insulation can create a passageway for water to enter the building, soaking the entire solar loop and lowering system performance. Silicone sealants, special adhesives, tapes, and mastics are to be used to seal all seams in outdoor pipe coverings. They must be sufficiently pliable to withstand constant thermal expansion and contraction.

All outside insulation must be covered with a substance impervious to ultraviolet degradation and moisture. Uncovered elastomer insulation will break down and crumble away in a very few years. A paint approved by the manufacturer can retard this process, but fresh paint is needed every 3-8 years. Several manufacturers of insulations are now offering ultraviolet-rated PVC, Do-all,and metal jacketing to go around their pipe insulations. These coverings are preferred since they are essentially inert and will not break down when exposed to ultraviolet light.

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedures

Verify that all insulation is resistant to ultraviolet degradation by checking the manufacturer's specifications. Inspect for holes, cuts, separations, or anything else along the insulation that may allow moisture to reach the interior of the insulation. Also check to ensure all insulation can withstand continuing thermal expansion and contraction.

15. **Inspect pipe supports to ensure that undue stress is not placed on piping (see Fig. 2-57).**

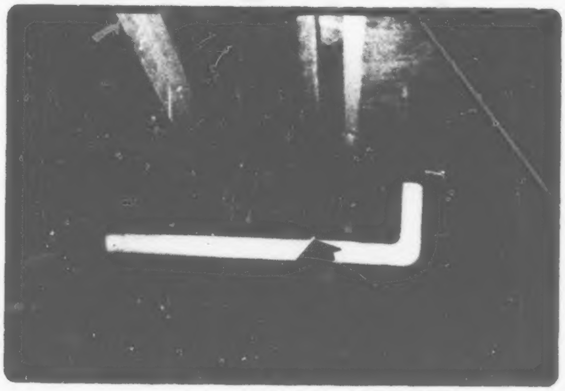

Figure 2-57. Pipe Supports

Background for Inspection

All pipes in solar loops must be checked to ensure that sufficient hangers have been installed. The HUD Installation Guidelines (p. 41) presents typical intervals for supports in solar hot water systems.

The UPC* establishes the following maximum spacing of pipe supports:

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*Uniform Plumbing Code, International Association of Plumbing and Mechanical Officials.

- Vertical Piping

copper pipe - 10-ft maximum
plastic pipe - sufficient to maintain straight alignment
galvanized pipe - at least every other story

- Horizontal Piping

Copper pipe - 6-ft intervals for pipe less than 1-1/2 in. diameter and 10-ft intervals for pipe over 2 in. in diameter
plastic pipe - 4-ft intervals or less
galvanized pipe - 10-ft maximum

The above requirements of the UPC are intended to maintain the integrity of the piping system. However depending on the type of pipe and insulation, the supports may have to be spaced closer than the UPC allowables.

In general, the pipe supports should be spaced to prevent buckling, dimpling or other distortion of the insulation cover. In addition, the pipe supports should provide for longitudinal slippage at the pipe support to compensate for expansion and contraction of the pipe without tearing, shredding or otherwise abrading the insulation or the cover.

The HUD/MPS (Section S-615-10.3) requires: "Provisions for expansion and contraction without undue strain or distortion shall be made as required by means of offset branches, expansion compensators, or flexible pipes. Piping shall be adequately supported to prevent undue strain on the flexible pipes and branches."

Where differences exist between the manufacturer's recommendations and the model code, the more stringent requirements should normally apply.

Special Tools Required

Visual inspection of pipe supports and spacing intervals should be adequate. A more thorough inspection can involve the use of a measuring tape to measure intervals between pipe hangers.

Inspection Procedures

Visually inspect both interior and exterior piping runs for pipe supports spaced and located per local code or UPC. Also inspect both interior and exterior piping runs for evidence of pipe sag between supports, evidence of abrasion or tearing of insulation jacket, and evidence of buckling or dimpling of insulation or jacket.

16. Ensure that a double-walled exchanger has been installed whenever nonpotable heat exchange fluids are used and/or when any local codes might call for one.

Background for Inspection

The HUD/MPS (Section S-515-9.1) requires: "When non-potable liquid is used in a solar energy system to transfer heat to domestic (potable) hot water, the design of the heat exchanger shall be such that either a minimum of two walls or interfaces are maintained between the non-potable liquid and the potable water supply or protection is provided in such a manner that equivalent safety is provided."

The Commentary to HUD/MPS Section S-515-9.1 states: "Commentary: Double wall heat exchanger designs are one way of meeting the intent of this criterion. When double wall heat exchanger designs consisting of two single wall heat exchangers in combination with an intermediary potable heat transfer liquid are used, leakage through one of the walls would result in a single wall configuration. Although this design is considered to meet the intent of this criterion, there are several other designs that avoid this problem. The use of single wall configurations which solely rely upon potable water pressure to prevent contamination is not considered to be an acceptable solution. Similarly, extra thick single walls are not considered to meet the intent of this criterion."

The meaning of the term "non-potable liquid" is not defined by HUD/MPS. However, its definition can be inferred by the following definition in Appendix D of the HUD/MPS: "Non-Potable Water: Water containing impurities in amounts sufficient to cause disease or harmful physiological effects and not conforming in its bacteriological and chemical quality to the requirements of the Public Health Service Drinking Water Standards or the regulations of the public health authority having jurisdiction."

A single wall heat exchanger is acceptable only when it is allowed by the local code. After the system has been installed, it is sometimes difficult to determine whether a single or double wall exchanger has been used. In such cases, it may be necessary to check with the installation contractor.

Special Tools Required

No special tools are required to conduct this inspection. The inspector, however, should be knowledgeable of local code requirements regarding the use of non-potable liquids.

Inspection Procedures

Verify that a permit has been issued for the solar installation and that the heat transfer fluid and the heat exchanger have been approved by the local code agency.

17. **Inspect the point of fill and drain for a label containing information about the type of heat exchange fluid used if other than tap water.**

Background for Inspection

HUD MPS requires that all heat transfer fluids be labeled. Labeling is necessary for a homeowner or inspector to know whether the criteria for single or double wall heat exchangers have been met. Additionally, however, it is important that the loop be labeled so that it can be properly checked and serviced over time and recharged with a compatible fluid if necessary. The circulated fluid from collectors to heat exchangers must be approved for use by local or other applicable codes.

The HUD/MPS (Section S-615-8.1.1) requires: "Drains and other designated fluid discharge or fill points in solar systems at which toxic, combustible, high temperature or high pressure fluids may be discharged, shall be labeled with a warning describing the identification and hazardous properties of the fluid, instructions concerning the safe handling of the fluid, and emergency first aid procedures.

> "Commentary: The original fluid containers will frequently be discarded after the system is charged. This action could result in no record of the fluid's properties being retained. The system drain is the point at which the owner or service personnel are most likely to contact the heat transfer fluid and permanent labeling should be retained at that point. Identification may be provided by attaching a tag containing the required information such as may be supplied by the heat transfer fluid manufacturer."

The CABO Model Solar Document* poses: "Drains in solar systems where high temperature, high pressures, or hazardous fluids are discharged shall have a warning label. For hazardous fluids, the label shall describe the hazardous properties of the fluid and emergency first aid procedures. Valves regulating such a discharge shall not be readily accessible to unauthorized personnel."

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedures

Visually check for labels near the point of fill or drain, for the type of heat exchange fluid used in the system.

18. In closed-loop systems, ensure that a pressure relief valve has been installed in the solar loop (see Figs. 2-58, 2-59).

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*Recommended Requirements to Code Officials for Solar Heating, Cooling, and Hot Water Systems, DOE/CS/34281-01, June 1980.

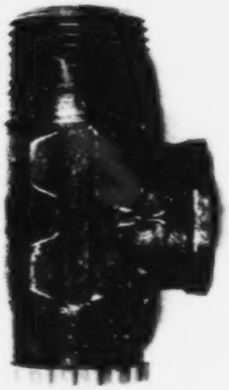

Figure 2-58. Pressure Relief Value

Figure 2-59. Pressure Relief Valve in a Closed-Loop System

Background for Inspection

Pressure relief valves must be installed on all closed-loop solar systems to prevent bursting of pipes or collectors. The valve allows the heat exchange fluid to escape when maximum working pressures are exceeded. Pressure relief valves are discussed on p. 54 of the HUD Installation Guidelines.

The HUD/MPS (Section S-615-10.11) requires: "Relief valves shall be piped to discharge to locations acceptable to the local administrative code authority having jurisdiction."

The UPC, Section 1007, requires: "The relief valve shall drain through a pipe to a point no less than 6 inches above the floor nor more than 2 feet above the floor."

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedure

Visually determine that a pressure relief valve has been installed in the solar loop and that the relief valve drains into a pipe which extends to a point no less than 6 in. above the floor nor more than 2 ft above the floor.

*Visually verify that the exposed end of the drain pipe is not threaded (preventing plugs from being inserted), and the relief valve is not leaking either at the valve body or at the exit from the drain line.

19. In closed-loop systems, ensure that a proper expansion tank has been installed in the solar loop (see Fig. 2-60.)

Figure 2-60. Expansion Tank

Background for Inspection

The purpose of an expansion tank in a closed-loop solar circulation system is two-fold:

- to protect the structural integrity of the collectors, piping and pump by providing a chamber into which the hot fluid can expand, and
- from which the cooled fluid can contract without admitting "new air" into the system.

Since closed-loop solar systems frequently utilize nonpotable fluids such as water/glycol, synthetic oils, silicone fluids and hydrocarbons, it is very important that:

- the expansion tank materials be compatible with the fluid used, and
- that the tank volume be adequate to contain the expanded fluid.

Expansion tanks for closed-loop systems are generally of two types:

- The more common type consists of a metallic chamber (aluminum, copper, stainless steel, steel), internally divided into two parts, separated by a thin pliable wall or diaphragm. One side of the pliable wall contains the expanded fluid; the other side contains a precharge of air (occasionally nitrogen) which serves to pressurize the chamber and thereby "support" the pliable wall. This type of expansion tank can generally be located anywhere in the system, but good practice indicates that it should be located close to the pump, be protected from pedestrian traffic and be accessible for periodic recharge of the air precharge.

- The second type of expansion tank consists of a high metallic chamber, located at or near the high point of the system, containing initially only a charge of air at atmospheric pressure. The expanded fluid from the piping enters the chamber and compresses the air, then, as the expanded fluid cools, the compressed air forces the fluid from the chamber back into the piping.

The HUD/MPS (Section S-615-19.9) requires: "Adequate provisions for the thermal expansion of solar heat transfer and storage liquid that would occur over the service temperature range shall be incorporated into the solar heating system design. Expansion tanks shall be sized in accordance with the recommendations of ASHRAE Guide and Data Book."

The HUD/Installation Guidelines note: "An expansion tank is a necessary component of a solar DHW system which has a closed circulation in the collector loop. As the temperature of the heat transfer fluid in the loop rises, the volume of fluid expands. The apparent expansion rate per degree rise will depend on the heat transfer fluid used.

For example, water has an apparent expansion rate of .025 percent per degree of temperature rise. A 50-gal volume of water at 60°F will expand to 51.75 gal at 200°F. The expansion tank must compensate for this variation in volume to keep system pressure below the maximum pressure allowed for the system components."

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedure

Verify by visual inspection that expansion tank is properly sized for fluid used, and tank materials are compatible with fluid use (per tank manufacturer's specifications).

*Verify expansion tank is properly located according to type.

20. In closed-loop systems, ensure that a pressure gauge has been installed in the solar loop in a visible position, downstream from the collector loop pump (see Figs. 2-61, 2-62).

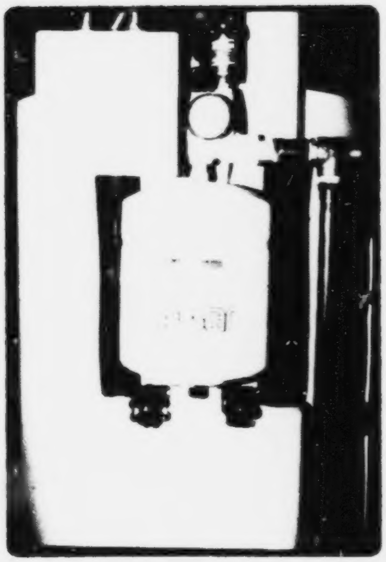

Figure 2-61. Pressure Gauge in the Solar Loop

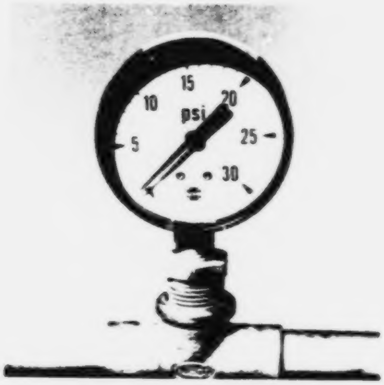

Figure 2-62. Pressure Gauge

Background for Inspection

A pressure gauge must be installed in the loop of a closed-loop solar system. This instrument is essential to ensure that the system has been properly charged with heat transfer fluid. It is also an important diagnostic tool for system service. The pressure gauge indicates total pressure, i.e., the sum of the liquid pressure heat, the initial pressure (precharge), and the pressure induced by the expanded fluid.

In certain instances, the pressure gauge can indicate "normal pressure" and still mask loss of fluid and/or initial charge, because of an offsetting increase in system pressure due to a significant rise in collector temperature.

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedures

Verify that pressure gauge has been installed and is convenient for periodic reading of the pressure.

21. **Ensure that a check valve is installed in closed-loop and recirculation systems to prevent thermosyphoning during periods of no collection. The check valve must be placed so that it allows flow in the direction of the circulator, but not the reverse (see Fig. 2-63).**

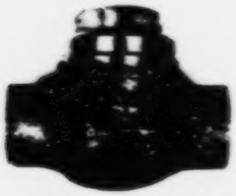

Figure 2-63. Swing Check Valve

Background for Inspection

Early experimentation with closed-loop systems showed that if a check valve is not installed in the loop, reverse thermosyphoning can occur at night, dissipating large amounts of the heat collected during the day. The check valve must be placed so that it allows flow in the direction of the circulator, but not the reverse.

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedure

Visually determine if the proper check valve has been installed, per design plans, and that it has been installed in the proper direction and proper place.

> Note: Swing check valves must be installed right-side up and in the horizontal mode. An arrow on the side of their body will indicate direction of allowable fluid flow.
>
> Note: Check valves are often hidden by pipe insulation and this insulation should not be removed or damaged while inspecting for check valve. It may help to review the system plans, and to test the system operation to be certain all components including the check valve function properly. (See Chapter 3: Assurance Testing and Troubleshooting.)

22. In thermosyphon systems, ensure that the top of the collectors is located below the storage tank and that there are no possible air traps in the piping between the collector and the tank.

Background for Inspection

HUD Installation Guidelines (p. 7) recommend that the bottom of the storage tank be positioned at least 18 in. to 24 in. above the top of the collectors. This is a good rule of thumb to follow when conventional components (tank, collectors, piping, etc.) are used. It should be noted however, that while some preengineered, prepackaged thermosyphon systems do not follow this 18 to 24 in. rule of thumb, due to special design and component considerations, thermal performance of the systems can be excellent none the less.

With roof-mounted collectors, the tank of a thermosyphon system is commonly located in the attic or placed outside and disguised by sheet metal to give the appearance of a chimney-like projection on the roof. In such systems, the copper tubes should be 3/4 in. inner diameter or larger to minimize water flow resistance. The tubing should be continuously sloping upwards to eliminate air pockets which, if formed, can cause flow stoppage. All piping also should be insulated.

Special Tools Required

No special tools are required to conduct this inspection. A measuring tape may be used to determine exact distances.

Inspection Procedure

Visually determine if the storage tank is located above the top of the collectors and check with manufacturer's specifications to insure proper distance between collectors and tank. Also inspect piping for proper insulation and gradual bends to insure there are no air traps or potential areas that can cause flow stoppage.

23. In draindown and drainback systems, check to see that the entire loop is pitched so as to allow complete drainage (see Fig. 2-64).

Background For Inspection

In draindown and drainback systems, protection from freezing depends completely on the total drainage of all water from the solar loop. Adequate pitch is usually considered to be 1/8 in./ft. Refer to p. 4 of the HUD Installation Guidelines for discussion.

Special Tools Required

A level can be used to determine if pipes are properly pitched.

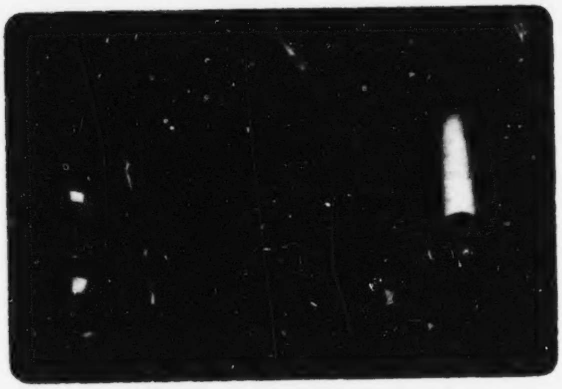

Figure 2-64. Pitched Piping

Inspection Procedure

Using a level. check the pitch of all piping from the bottom of the collector to drainage point or holding tank. Be sure to check even the shortest of pipes for these areas, if not pitched, it can impair drainage from the solar loop.

24. Check to ensure that vacuum breakers are used according to local code (see Fig. 2-65).

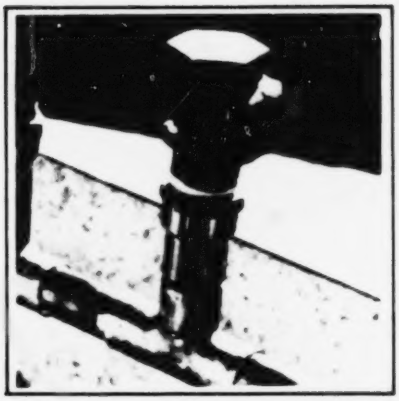

Figure 2-65. Vacuum Breaker

Background For Inspection

HUD MPS calls for the use of vacuum relief whenever tanks or pipes might collapse from vacuum.

The primary function of the vacuum break is to admit air to the collectors and associated plumbing, to allow rapid drainage of the liquid (water) within the collectors and plumbing to preclude freezing, and consequential mechanical rupture of collector and pipe materials.

Vacuum breaks, i.e., valves, generally have brass or bronze bodies with an integral spring-actuated device, with a preset load on a pliable seat, which is unloaded by the internal vacuum induced by the draining liquid. The vacuum valve will automatically reset when equilibrium is reached between the preset load and ambient pressure. Refer to p. 56 of the HUD Installation Guidelines for discussion.

Special Tools Required

No special tools are required to conduct this inspection. Knowledge of relevant local codes is necessary.

Inspection Procedures

Visually determine if vacuum relief valve has been installed as per local code, especially in draindown and certain drainback systems. Generally, a vacuum relief valve will be installed at the high point of the collector piping above the collectors. A vacuum relief valve is often installed above the cold water inlet of storage tanks to eliminate vacuum conditions that could collapse the tanks.

25. **Ensure that backflow preventers are used according to local code and that they are properly vented in all cases. If a backflow preventer is used, ensure that an expansion tank is installed between that valve and the storage tank (see Fig. 2-66).**

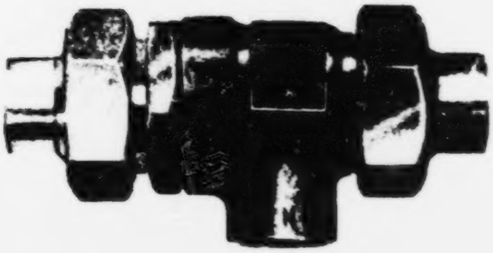

Figure 2-66. Backflow Preventer

Background for Inspection

Certain code jurisdictions require backflow preventers to prevent contamination of the potable water supply in the event of leakage from the solar loop.

When backflow preventers are used, it is good practice to install an expansion tank between the valve and the storage vessel. The purpose of this expansion tank is to accommodate volumetric expansion of the water in the storage tank when heating takes place without unnecessarily activating the temperature pressure relief valve. The expansion tank must be compatible with potable water.

Special Tools Required

No special tools are required to conduct this inspection. Knowledge of relevant local codes is necessary.

Inspection Procedure

Visually determine if backflow preventers have been installed properly per local code, where applicable. Check to ensure that an expansion tank, compatible with potable water has been installed between the backflow preventer valve and the storage tank.

*A check valve is not a substitute for an approved backflow preventer and should NOT be used in its place.

26. Ensure that a combination temperature/pressure relief valve is used on all pressurized storage vessels, and check to be sure that the vent line is properly placed to allow venting to a drain, to the exterior, or to a sewer, as required by local code (see Figs. 2-67, 2-68, 2-69).

Background for Inspection

A combination temperature/pressure relief valve must be installed on all pressurized storage vessels. (Refer to p. 54 of the HUD Installation Guidelines). The purpose of a combination temperature and pressure relief valve is to protect the storage tank and associated plumbing from excessive temperature and pressure. Combination temperature and pressure (T&P) relief valves should be matched to the circulated fluid per fluid/collector manufacturer recommendations.

Circulated fluids such as water/ethylene glycol are toxic and therefore the T&P valve must be located to prevent venting onto the ground or into the sewer. When toxic fluids are used, venting should be into a suitable container, properly marked as containing hazardous fluid, and should be isolated from children and pets. Local codes may define the manner of acceptable venting.

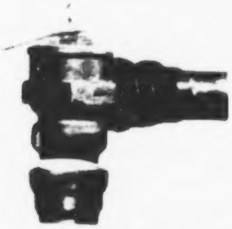

Figure 2-67. Temperature/Pressure Relief Valve

Figure 2-68. Temperature/Pressure Relief Valve Tank on a Pressurized Storage

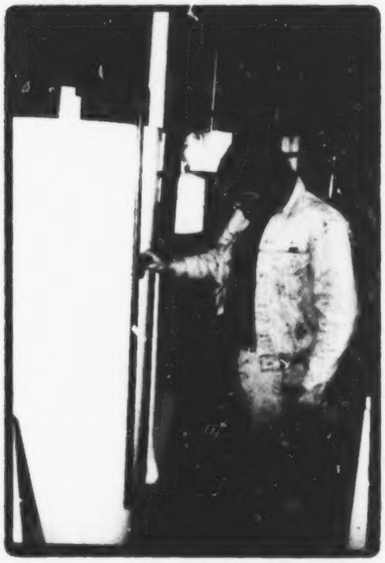

Figure 2-69. Vent Line from Pressurized Storage Tank

WARNING: Operating a hot water tank or two tanks in series without a temperature and pressure relief valve is extremely dangerous and is ILLEGAL IN MOST AREAS. Check your local building codes carefully on this point."

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedure

Visually determine that a properly matched temperature and pressure relief valve, as determined by manufacturer's specification, is installed on or near the top of both a preheater tank and heater tank, and that the vent line drains to a point no less than 6 in. above the ground nor more than 2 ft above the floor, unless local codes require more stringent specifications. Also check to ensure the exposed end of the vent pipe is not threaded.

*Visually verify that the relief valves are not leaking either at the valve body or at the exit from the vent pipe.

*Determine by review of permit and installer data the type of circulating fluid being used and manufacturer's recommendations for temperature and pressure relief settings; frequently, both the fluid and collector manufacturers will have recommendations.

27. **Ensure that a device such as a tempering or mixing valve has been provided to limit the temperature of the hot water to a maximum of 140° for personal use at fixtures (see Fig. 2-70).**

Background for Inspection

HUD MPS (S-615-10.6) calls for a tempering valve with all solar domestic hot water systems. (Refer to p. 54 of the HUD Installation Guidelines). The reason for this valve is that solar storage tanks can obtain temperatures approaching 200°, especially during prolonged periods of summer sunshine and low hot water demand. If the water is allowed to be delivered to the faucet at these temperatures, there is a possibility of scalding the user.

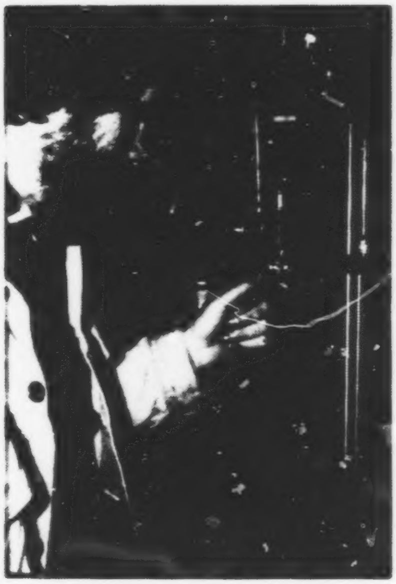

Figure 2-70. Mixing Valve

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedure

Visually determine if a tempering or mixing valve has been installed below the hot water outlet with cold water entering from the bottom.

28. **Inspect the wiring to the controller and/or pump to insure that all 120V wiring is installed in rigid or flexible conduit, or per local code.**

Background for Inspection

The National Electric Code (NEC), Article 400 - Flexible cords and cables, specifies cords and cables by materials, fabrication techniques, and locations of use, i.e., damp places, dry places, hazardous locations, nonhazardous locations. In general, flexible cords are allowable when connecting nonstationary appliances to wall outlet (refrigerators, washers) or to power stationary appliances (furnace blowers, pumps) which can require frequent maintenance or replacement.

In no instance, according to the NEC, may a flexible cord pass through a wall, window, or door opening, or be concealed within a wall, ceiling, or floor.

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While the NEC does not specifically limit the length of an appliance cord. local codes may; but if not, good practice would indicate practical limits to insure safety of children,in particular.

Local code agencies generally impose additional requirements on cords such as "limited to 4-6 feet length"; "may not block door or window openings"; "may not be in obvious path of persons or animals."

In all instances specifically prohibited (as above), appliance cords should not be used and the controller and/or pump should be powered and switched by wires contained within rigid or flexible conduit.

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedure

Visually determine if location of pump and controller preclude use of appliance cords for power due to hazard to people (distance, routing) or to structure (through walls, windows, doors). If this is the case, assure that power is supplied to controller and/or pump in an approved manner, e.g., in rigid or flexible conduit, suitably switched.

29. Inspect the 220V feed to any electric water heater or ensure that it is installed in rigid or flexible conduit, or per local code.

Background for Inspection

The NEC, Section 310-7, Wet Locations, requires that the wiring to an electric water heater be installed within rigid or flexible metallic conduit.

The NEC, Section 4-21, requires all permanently connected appliances to be protected with a separate circuit breaker or fused disconnect switch.

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedures

Visually verify that the power wiring to the electric DHW heater is installed within either rigid or flexible metallic conduit.

*Visually verify that the circuit to the electric DHW heater is on a separate circuit protected by a circuit breaker or is protected by a fused disconnect switch.

30. Ensure that the pump isolation valves are installed so as to facilitate pump repair. These valves may be integral with the pump flange fitting (see Fig. 2-71).

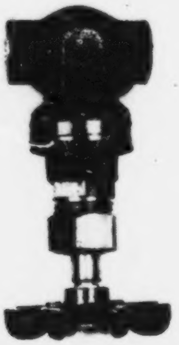


Figure 2-71. Typical Isolation Valve

Background for Inspection

Lumps used on residential solar systems are generally less than 1/4 horse-power and are mounted "in line" with the piping. Since pumps are among the few moving parts on typical solar systems, it can be expected that their operating lives will be somewhat less than other system components. Pump replacement is greatly facilitated, and therefore less costly, if isolation valves are installed on both sides of the pump housing. Many pump manufacturers furnish isolation valves integral to the pump mounting flanges.

> Note: It is considered good practice to utilize the pump isolation valves as the only means to charge or drain closed-loop systems utilizing toxic fluids, and thereby preclude exposing others to the safety hazards of the fluid.

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedure

Verify pump has either integral flange isolation valves or separate valves on both sides of the pump. In general, the separate valves should be within a few inches of the pump.

31. Insure that an air vent has been installed in the solar loop piping (see Fig. 2-72).

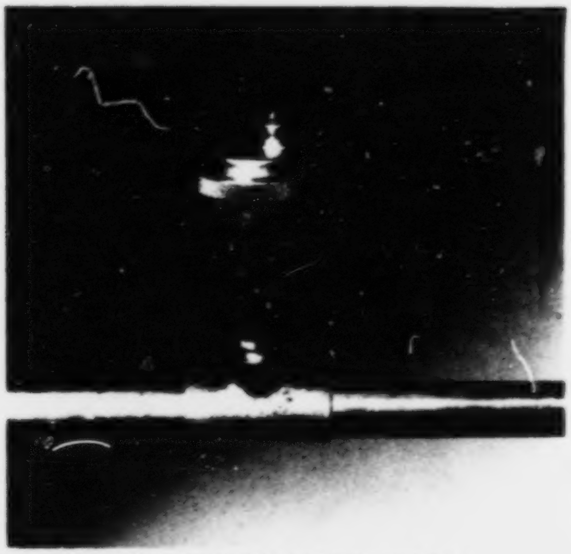


Figure 2-72. Air Vent in Solar Loop Piping

Background for Inspection

The purpose of an air vent is to allow air trapped within the collector and associated plumbing to escape automatically as the collector is initially filled with fluid and each time it is refilled after draindowns (freeze protection) or periodic maintenance on pump, tank, or such. Certain types of drainback systems do not require air vents, but omission must be verified by the manufacturer's specifications.

The air vent should be located at the high point of the collector/plumbing, and is often adjacent to the vacuum breaker valve. An additional air vent placed in an air eliminator is often installed in the solar loop plumbing near the storage tank.

Several manufacturers now combine the functions of vacuum break and air venting into a single valve.

> Caution: Since air vents purge both air and fluid vapors from the collector/plumbing loop, they can become inoperative if the circulating fluid has a tendency to gum in the presence of ambient air (oils/paraffins) or if the valve internal seat is contamininated by bits of solder, flux,or other debris transported by the circulated fluid. Therefore, they should be inspected periodically and replaced if proper functioning cannot be verified.

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedure

Visually determine if an air vent has been installed at the high point of the collector plumbing. Consult manufacturer's specifications to determine if an air eliminator is required to be installed in the solar loop plumbing near the storage tank(s).

32. In draindown systems, check to insure that solenoid valves are properly installed. One, normally closed, should be in the feed line of the collector loop and one, normally open, in the draindown portion of the collector loop (see Fig. 2-73).

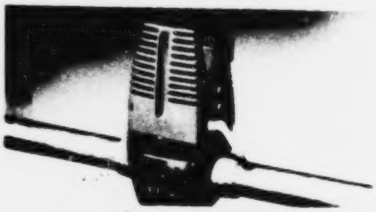


Figure 2-73. Solenoid Valve

Background for Inspection

Solenoid valves are electrically operated valves used in a draindown system to start and stop (as well as divert) the flow of heat transfer fluid. Most draindown systems use two such valves: one normally open and one normally closed. When a freezing condition exists or electrical power fails, the valve which allows fluid to circulate to the collectors closes and the valve used to drain the system opens. This procedure is reversed when the weather is warm and sunny. Solenoid valves may require some regular maintenance. In regions with infrequent freezing, their operations should be checked occasionally.

Special Tools Required

No special tools are required to conduct this inspection.

Inspection Procedure

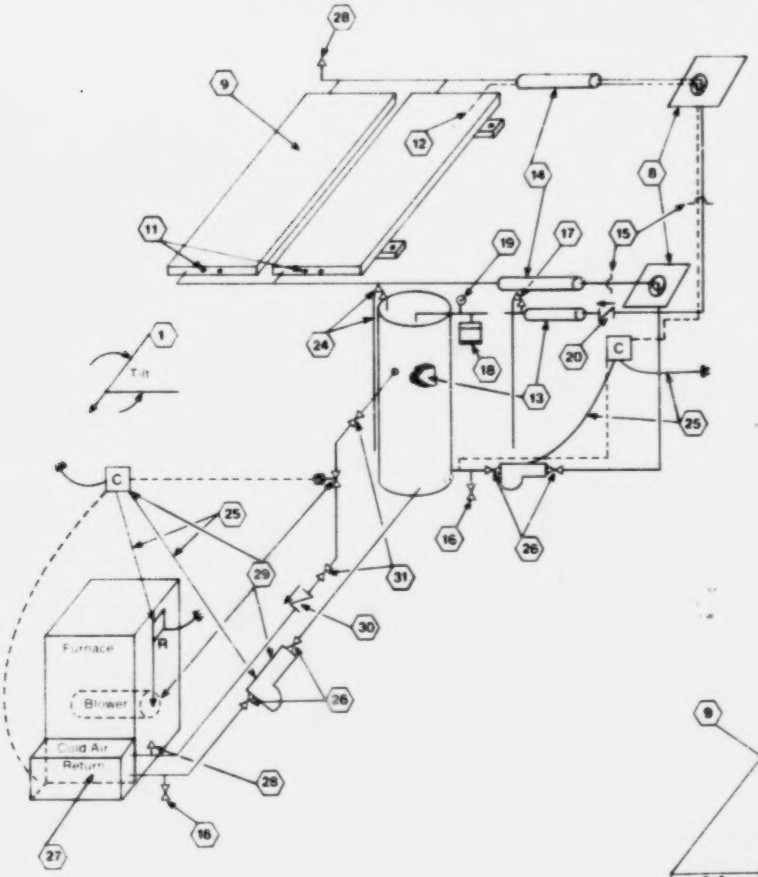
Visually determine if a solenoid value has been installed in the feed line of the collector loop, and another in the draindown portion of the collector loop, or as indicated in manufacturer's specifications.

> Note: A recently introduced solenoid valve combines the functions of the above two valves. This valve should be more reliable than the valves it replaces, for any time the number of compononts in a system is reduced, system reliability increases.

However, field performance data is not yet available on this product, and for the purposes of this inspection process, the two valve set-up is the only type discussed.

BEST DOCUMENT AVAILABLE SP-1130

Checkpoints for Solar Space Heating Systems (liquid only)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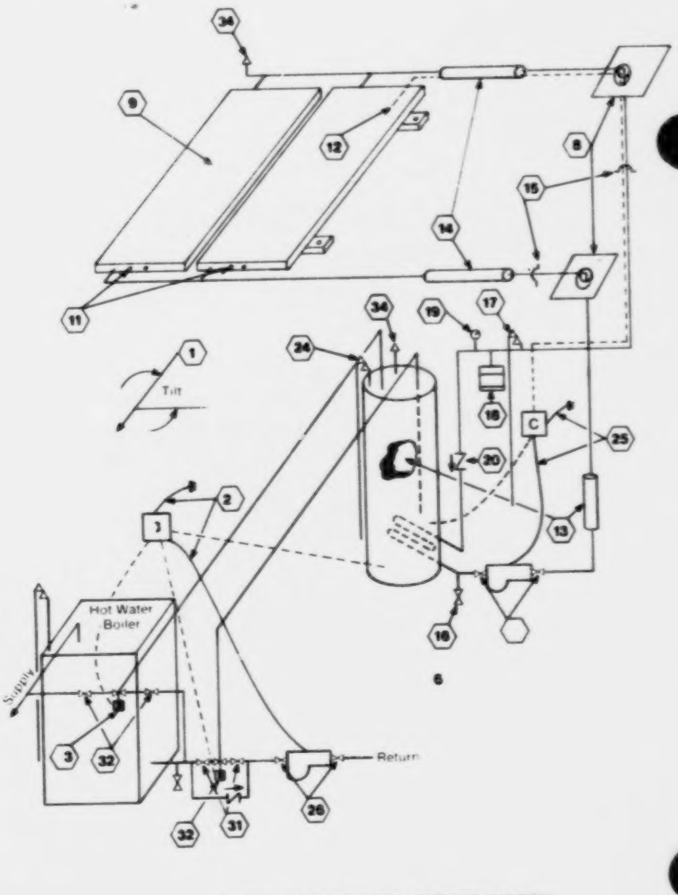
ACTIVE SOLAR SPACE HEATING SYSTEM
Forced Air — Closed Loop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Hot Water Boiler
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ACTIVE SOLAR SPACE HEATING SYSTEM
Hot Water — Closed Loop

2.6.2 Solar Space Heating Systems (liquid only)

1. **Observe the orientation of the collectors to ensure that they face within 45° of true south. Observe the tilt angle to ensure that it is equal to or greater than local latitude.**

See Discussion of SDHW Inspection Checkpoint #1.

> Note: RCS Program regulations call for largely similar collector orientation and tilt angle parameters for solar domestic hot water, solar space heating, and solar pool heating. It should be noted, however, that common solar space heating design and installation practice calls for more strict attention being paid to orientation (±30° of true south) and much steeper tilt angles (many manufacturers suggest local latitude +15°). This is because special care must be taken to capture radiation from the low winter sun. Solar angles are discussed more fully in Section 2.3.2.

2. **Observe the sun's path relative to the collectors to ensure that the collection area is not shaded from 9:00 am to 3:00 pm during the months of peak load.**

See Discussion of SDHW Inspection Checkpoint #2.

3. **Inspect the standoff between the collectors and the roof to ensure that there is a minimum of 1-1/2 in. of clearance. (Local codes could dictate a greater or lesser clearance.) If the collectors are mounted directly on the roof surface, check to ensure that proper flashing has been used to prevent leakage, mildew, and ice buildup. Adequate clearance from any combustible material must also be provided.**

See Discussion of SDHW Inspection Checkpoint #3.

4. **Inspect the collector rack, if any, to ensure that it is structurally sound, weather resistant, and that compatible materials have been used.**

See Discussion of SDHW Inspection Checkpoint #4.

5. **Inspect the anchorage of the rack or the individual collector standoffs to the roof to ensure that blocking, spanner mounting, or direct lagging into rafters has been used and has not caused leaks in the roof.**

   See Discussion of SDHW Inspection Checkpoint #5.

6. **Ensure that any additional wind, snow,or seismic loadings of the collectors do not cause the building to violate local codes.**

   See Discussion of SDHW Inspection Checkpoint #6.

7. **Ensure that any home entrances are protected from snow slides in areas with snow loads of 20 lb/ft^2. In areas where snow loads are greater than 20 lb/ft^2 (check with local codes), the placement of collectors directly over entrances should be avoided. However, if there is no option, a strong deflector should be attached in a structurally sound manner.**

   See Discussion of SDHW Inspection Checkpoint #7.

8. **Inspect the roof for flashing anchorage, caulking, and replacement roofing to ensure that all penetrations are watertight. Inspect for a flexible and watertight seal on the solar loop penetrations.**

   See Discussion on SDHW Inspection Checkpoint #8.

9. **Ensure that collectors are safety-glazed or otherwise protected in ground- or wall-mounts with glazings less than 45° and those within 6 ft of the ground.**

   See Discussion of SDHW Inspection Checkpoint #9.

10. **Verify that the collectors have been tested according to ASHRAE 93-77. A label may be attached to the collectors containing this information. If not, the model name and/or model number on the collectors will help in a verification investigation.**

    See Discussion of SDHW Inspection #10.

11. **Ensure that the collectors are undamaged and placed for proper flow and drainage. Weep holes must face the bottom.**

See Discussion of SDHW Inspection Checkpoint #11.

12. **Inspect for weather protection of all outdoor sensors, sensor wire, and wire splices. Ensure that sensors are not mounted on the outside of the case or on the roof.**

See Discussion of SDHW Inspection Checkpoint #12.

13. **Inspect all pipe insulation for a minimum R-value of 4. All piping over 1 in. should be insulated to R-6. Storage tanks must be insulated to a minimum of R-11.**

See Discussion of SDHW Inspection Checkpoint #13.

14. **Inspect outside insulation for waterseal and for ultraviolet inhibition. Rigid fiberglass pipe insulation should be wrapped with weather-protective material. Elastomer insulation must be painted with a flexible finish or wrapped to prevent ultraviolet degradation.**

See Discussion of SDHW Inspection Checkpoint #14.

15. **Inspect pipe supports to ensure that undue stress is not placed on piping.**

See Discussion of SDHW Inspection Checkpoint #15.

16. **Inspect the point of fill or drain for a label containing information about the type of heat exchange fluids used if other than tap water.**

See Discussion of SDHW Inspection Checkpoint #16.

17. In closed-loop systems, ensure that a pressure relief valve has been installed in the solar loop.

See Discussion of SDHW Inspection Checkpoint #18.

18. In closed-loop systems, ensure that an expansion tank has been installed in the solar loop.

See Discussion of SDHW Inspection Checkpoint #19.

19. In closed-loop systems, ensure that a pressure gauge has been installed (in a visible position) in the solar loop.

See Discussion of SDHW Inspection Checkpoint #20.

20. Ensure that a check valve is installed to prevent thermosyphoning during periods of no collection. The check valve must be placed so that it allows flow in the direction of the circulator, but not the reverse.

See Discussion of SDHW Inspection Checkpoint #21.

21. In thermosyphon systems, ensure that the top of the collectors is located below the storage tank and that there are no possible air traps in the piping between the collector and the tank.

See Discussion of SDHW Inspection Checkpoint #22.

22. In draindown and drainback systems, check to be sure that the entire loop is pitched so as to allow complete drainage. Adequate pitch is usually considered to be 1/4 in. in 4 ft.

See Discussion of SDHW Inspection Checkpoint #23.

23. Check to ensure that vacuum breakers are used according to local code.

See Discussion of SDHW Inspection Checkpoint #24.

24. Ensure that a combination temperature/pressure relief valve is used on all pressurized storage vessels, and check to be sure that the vent line is properly placed to allow venting to a drain, to the exterior, or to a sewer, as required by local code.

See Discussion of SDHW Inspection Checkpoint #26.

25. Inspect the wiring to the controller and/or pump to insure that all 120V wiring is installed in rigid or flexible conduit, or per local code.

See Discussion of SDHW Inspection Checkpoint #28.

26. Ensure that the pump isolation valves are installed so as to facilitate pump repair. These valves may be integral with the pump flange fitting.

See Discussion of SDHW Inspection Checkpoint #30.

Forced Air Space Heating Systems

27. Ensure that the heat exchanger is located correctly, e.g., in a return air plenum or duct according to manufacturer's specifications:

- ensure that the heat exchanger is protected by upstream air filter.
- with the furnace blower operating, assure that the heat exchanger is installed "air tight".

Background for Inspection

The positioning of the water-to-air heat exchanger is critical for the effective operation of a water storage/air distribution solar space heating system. In the vast majority of cases, the heat exchanger is placed in the return (cool) air trunk before the conventional heater. Such placement allows the solar system to contribute to the heating load down to the lowest possible temperature.

To ensure the long-term efficiency of the heat exchanger, it should be kept clean with a filter. This filter must be located upstream of the heat exchanger in order to be effective.

A major consideration in the installation of any solar air delivery system is the huge potential for leaks at the many seams in ducting systems. Sloppy installation techniques will quickly destroy the benefit of solar collection.

Special Tools Required

None.

Inspection Procedure

Inspect the return air trunk visually for proper placement of the heat exchanger and the filter.

The integrity of the heat exchanger's seams can often be checked by turning on the furnace blower so that air is circulating through the system.

28. **Ensure that an air vent is provided so that air which may become trapped in lines and the heat exchanger can be vented automatically.**

Background for Inspection

As with any hydronic system, the storage-to-heat-exchanger loop must include an air eliminator to allow trapped air within the piping to escape automatically. Otherwise, air blockages could result in serious decreases in the performance of the heat exchanger.

Special Tools Required

None.

Inspection Procedure

Inspect the storage-to-heat-exchanger loop for the inclusion of an air eliminator of some kind. Air vents are often placed at high points in the piping.

29. Cycle the furnace blower on and off to ensure that the furnace blower and controller are interlocked such that the pumps and solenoid valve operate only when the existing furnace blower is operating.

Background for Inspection

Central to the operation of a water storage/air distribution solar system is the proper interconnection of the solar storage system with the conventional heater. When heat is needed, solar-derived hot water from the storage tank is circulated through a water-to-air heat exchange coil in the return air trunk, upstream of the furnace. The blower in the furnace will simultaneously draw air through the duct system, across the heat exchanger, and back into the home. The furnace itself will not turn on as long as the solar heat exchange coil can provide sufficient temperatures.

The most common method of controlling these modes is with a two-stage thermostat. The first stage controls solar heat alone; the second stage controls solar and the backup furnace.

Special Tools Required

None.

Inspection Procedure

The most basic test of the proper operation of the system is to cycle the furnace blower on and off to ensure that the solar heat exchanger loop responds with circulation. If this interconnection does not occur, the system cannot perform properly.

30. Ensure that a proper valve is supplied in the hot water supply line to preclude thermosyphoning. Normally, the valve must be closed.

Background for Inspection

As is the case with solar storage-to-collector loops (refer to Inspection Point #21, Domestic Hot Water), a solar storage-to-heat-exchanger loop must not be allowed to thermosyphon naturally when heat transfer is not called for. A solenoid or check valve must be installed to prevent this possibility.

Special Tools Required

None.

Inspection Procedure

Visually inspect the storage-to-heat-exchanger loop for a solenoid or check valve.

31. Ensure that an isolation valve is provided so that the solenoid valve can be repaired or replaced without draining lines or heat exchanger.

Background for Inspection

As is the case in Inspection Point 30 of Domestic Hot Water, it is advantageous in the installation of solar systems to provide means to facilitate repair of components known to be occasionally troublesome such as solenoid valves.

Special Tools Required

None.

Inspection Procedure

Check for a means of isolation close to the side of a solenoid valve.

Hot Water Space Heating Systems

32. **Ensure that the mode selector solenoid valve is located in a parallel loop with space heating hot water return (S.H. HWR), to allow boiler operation during valve repair. Normally, the solenoid valve must be open to the supply.**

Background for Inspection

The positioning of the mode selector solenoid valve is critical for uninterrupted operation of the backup heating system during times when solar system components are under repair. Solenoid valves in particular require periodic maintanence and should be able to be isolated from the backup system.

Special Tools Required

None.

Inspection Procedure

Visually inspect solenoid valves to ensure the installation of by-pass or isolation valves on each side of the solenoid valve.

33. **Ensure that the differential solenoid valve is located in a series loop of the boiler-preheater line to preclude S.H. HWR temperature. Normally, the solenoid valve must be closed to the boiler.**

Background for Inspection

This 3-way solenoid valve provides solar preheated water when its is higher than the minimum working temperature. When the temperature of the solar is not adequate the solenoid valve closes preventing the lower temperature solar water access to the system while allowing the S.H. HWR to feed the system.

Special Tools Required

None.

Inspection Procedure

Visually inspect to ensure that the differential solenoid valve is properly located in a series loop of the boiler-preheater line and that all wires are properly connected to the solenoid valve and the solar tank.

34. Ensure that an air vent has been installed above the storage tank to preclude air pockets.

Background for Inspection

It is essential that air be eliminated from within the system or else severe damage to the pump and other components could occur. The air vent, or eliminator, should be located at the highest point above the tank piping.

Special Tools Required

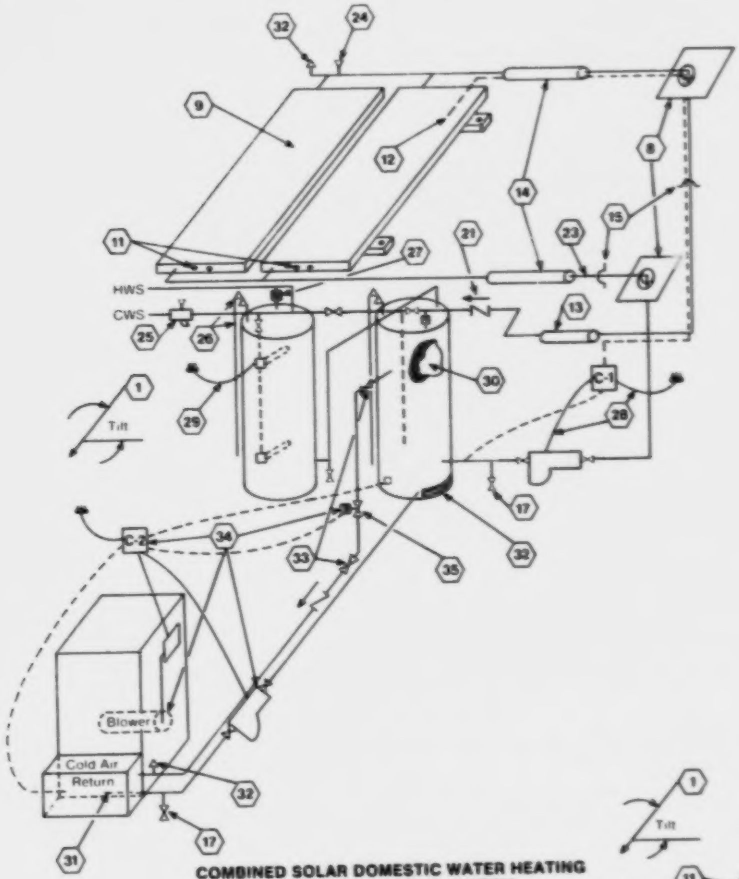
None.

Inspection Procedure

Visually ensure the proper placement of an automatic air vent as described above.

*To inspect for proper functioning of the air vent remove the cap and press down firmly on the stem of the valve until a few drops of liquid discharge from the valve. (Note: this is the same type of valve stem that is used in common automobile tires.) Replace cap, tighten by hand and leave 1/2 turn loose.

Checkpoints for Combined Solar Domestic Water Heating and Space Heating Systems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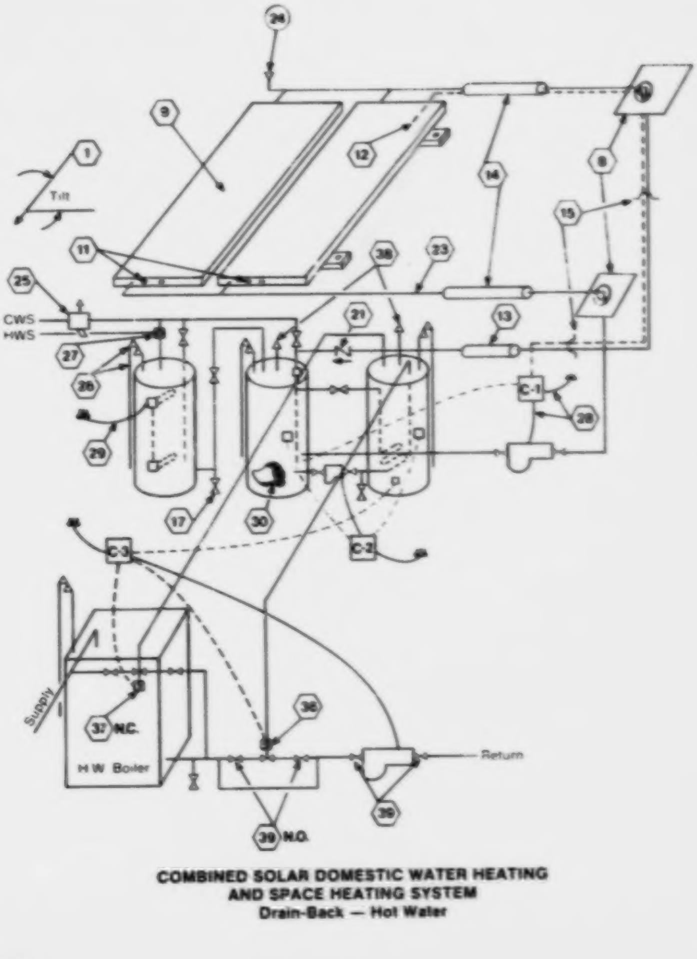
COMBINED SOLAR DOMESTIC WATER HEATING AND SPACE HEATING SYSTEM
Drain-Back — Forced Air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H W Boiler
Return
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COMBINED SOLAR DOMESTIC WATER HEATING AND SPACE HEATING SYSTEM
Drain-Back — Hot Water

2.6.3 Combined Solar Domestic Water Heating and Space Heating Systems (liquid only)

1. **Observe the orientation of the collectors to ensure that they face within 45° of true south. Observe the tilt angle to ensure that it is equal to or greater than local latitude.**

   See discussion of Solar Space Heating Systems (Liquid Only), Checkpoint #1.

2. **Observe the sun's path relative to the collectors to ensure that the collection area is not shaded from 9:00 am to 3:00 pm year round.**

   See discussion of SDHW Checkpoint #2.

3. **Inspect the standoff between the collectors and the roof to ensure that there is a minimum of 1-1/2 inches of clearance. (Local codes could dictate a greater or less clearance). If the collectors are mounted directly on the roof surface, check to ensure that proper flashing has been used to prevent leakage, mildew, and ice buildup. Adequate clearance from any combustible material must also be provided.**

   See discussion of SDHW Checkpoint #3.

4. **Inspect the collector rack, if any, to ensure that it is structurally sound, weather resistant, and that compatible materials have been used.**

   See discussion of SDHW Checkpoint #4.

5. **Inspect the anchorage of the rack or the individual collector standoffs to the roof to ensure that blocking, spanner mounting, or direct lagging into rafters has been used and has not caused leaks in the roof.**

   See discussion of SDHW Checkpoint #5.

6. Ensure that any additional wind, snow, or seismic loadings of the collectors do not cause the building to violate local codes.

   See discussion of SDHW Checkpoint #6.

7. Ensure that any home entrances are protected from snow slides in areas with snow loads of 20 lb/ft^2. In areas where snow loads are greater than 20 lb/ft^2 (check with local codes), the placement of collectors directly over entrances should be avoided. However, if there is no option, a strong deflector should be attached in a structurally sound manner.

   See discussion of SDHW Checkpoint #7.

8. Inspect the roof for flashing anchorage, caulking, and replacement roofing to ensure that all penetrations are watertight. Inspect for flexible and watertight seal on the solar loop penetrations.

   See discussion of SDHW Checkpoint #8.

9. Ensure that collectors are safety-glazed or otherwise protected in ground or wall mounts with glazings less than 45° and those within 6 ft of the ground.

   See discussion of SDHW Checkpoint #9.

10. Verify that the collectors have been tested according to ASHRAE 93-77. A label may be attached to the collectors containing this information. If not, the model name and/or model number on the collectors will help in a verification investigation.

    See discussion of SDHW Checkpoint #10.

11. **Ensure that the collectors are undamaged and placed for proper flow and drainage. Weep holes must face the bottom.**

    See discussion of SDHW Checkpoint #11.

12. **Inspect for weather protection of all outdoor sensors, sensor wire, and wire splices. Ensure that sensors are not mounted on the outside of the case or on the roof.**

    See discussion of SDHW Checkpoint #12.

13. **Inspect all pipe insulation for a minimum R-value of 4. All piping over 1 in. should be insulated to R-6.**

    See discussion of SDHW Checkpoint #13.

14. **Inspect outside insulation for waterseal and for ultraviolet inhibition. Rigid fiberglass pipe insulation should be wrapped with weather-protective material. Elastomer insulation must be paned with a flexible finish or wrapped to prevent ultraviolet degradation.**

    See discussion of SDHW Checkpoint #14.

15. **Inspect pipe supports to ensure that undue stress is not placed on piping.**

    See discussion of SDHW Checkpoint #15.

16. **Ensure that a double-walled heat exchanger has been installed whenever non-potable heat exchange fluids are used and/or when any local codes might call for one.**

    See discussion of SDHW Checkpoint #16.

17. **Inspect the point of fill or drain for a label containing information about the type of heat exchange fluids used if other than tap water.**

See discussion of SDHW Checkpoint #17.

18. **In closed loop systems, ensure that a pressure relief valve has been installed in the solar loop.**

See discussion of SDHW Checkpoint #18.

19. **In closed loop systems, ensure that an expansion tank has been installed in the solar loop.**

See discussion of SDHW Checkpoint #19.

20. **In closed-loop systems, ensure that a pressure gauge has been installed (in a visible position) in the solar loop.**

See discussion of SDHW Checkpoint #20.

21. **Ensure that a check valve is installed to prevent thermosyphoning during periods of no collection. The check valve must be placed so that it allows flow in the direction of the circulator, but not the reverse.**

See discussion of SDHW Checkpoint #21.

22. **In thermosyphon systems, ensure that the top of the collectors is located below the storage tank and that there are no possible air traps in the piping between the collector and the tank.**

See discussion of SDHW Checkpoint #22.

23. In draindown and drainback systems, check to be sure that the entire loop is pitched so as to allow complete drainage. Adequate pitch is usually considered to be 1/4 in. in 4 ft.

See discussion of SDHW Checkpoint #23.

24. Check that vacuum breakers are used according to local code.

See discussion of SDHW Checkpoint #24.

25. Ensure that backflow preventers are used according to local code and that they are properly vented in all cases.

See discussion of SDHW Checkpoint #25.

26. Ensure that a combination temperature/pressure relief valve is used on all pressurized storage vessels, and check to be sure that the vent line is properly placed to allow venting to a drain, to the exterior, or to a sewer, as required by local code.

See discussion of SDHW Checkpoint #26.

27. Ensure that a device such as a tempering or mixing valve has been provided to limit the temperature of the hot water to a maximum of 140° for personal use at fixtures.

See discussion of SDHW Checkpoint #27.

28. Inspect the wiring to the controller and/or pump to insure that all 120V wiring is installed in rigid or flexible conduit, or per local code.

See discussion of SDHW Checkpoint #28.

29. Inspect the 220V feed to any electric water heater to ensure that it is installed in rigid or flexible conduit, or per local code.

See discussion of SDHW Checkpoint #29.

30. Ensure that the solar storage tank is insulated to R-11, or according to specifications set by the heat exchanger manufacturer. Check the insulation installation for damage and closeness of fit.

See discussion of SDHW Checkpoint #13.

Forced-Air Space Heating Systems

31. Ensure that the heat exchanger is located correctly, e.g., in a return-air plenum or duct per the manufacturer's specification:

- ensure that the heat exchanger is protected by an upstream air filter, and
- with the furnace blower operating, ensure that heat exchanger is installed "air tight."
- See discussion of Forced Air Space Heating Checkpoint #27.

32. Ensure that an air vent is provided so that air trapped in lines and heat exchanger can be vented automatically.

See discussion of SDHW Checkpoint #31.

33. Ensure that an isolation valve is provided so that the solenoid valve can be repaired or replaced without draining lines or heat exchanger.

See discussion of Solar Space Heating Checkpoint #31.

34. **Cycle the furnace blower on and off to ensure that the furnace blower and controller are interlocked, so that pumps and solenoid valve operate only when existing furnace blower is operating.**

See discussion of Solar Space Heating Checkpoint #29.

35. **Ensure that a proper valve has been provided in the hot water supply to the heat exchanger. The valve must be of the type specified by the manufacturer.**

See discussion of Solar Space Heating Checkpoint #30.

Hot Water Space Heating Systems

36. Ensure that the mode selector solenoid valve is located in a parallel loop with S.H. HWR, to allow boiler operation during valve repair. Normally, the solenoid valve must be open.

See discussion of Solar Space Heating Systems, Checkpoint #32.

37. Ensure that the differential solenoid valve is located in the series loop of the boiler-preheater line to preclude S.H. HWR temperature. Normally, the solenoid valve must be closed.

See discussion of Solar Space Heating Systems, Checkpoint #33.

38. Ensure that an air vent has been installed above the storage tank to preclude air pockets.

See discussion of Solar Space Heating Systems, Checkpoint #34.

39. Ensure that isolation valves are provided so that the solenoid valve can be repaired or replaced without having to drain lines.

Background for Inspection

Inspect to ensure the proper placement of isolation valves such that the solenoid valve can be isolated without having to drain lines, thereby eliminating the need for re-charging the entire system.

Special Tools Required

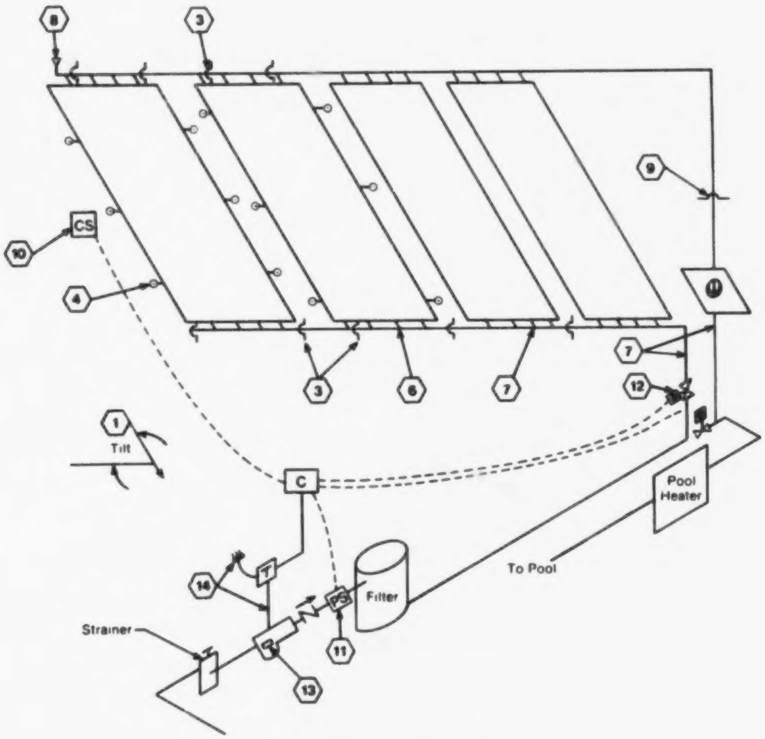
None.

Inspection Procedure

Visually inspect to ensure proper placement of isolation valves on both sides of the solenoid valve.

*To inspect for proper function of the isolation valves, check to ensure they are free and not jambed open or shut. When in an open position, the valve should be backed off 1/4 turn from completely open.

Checkpoints for Solar Swimming Pool Heaters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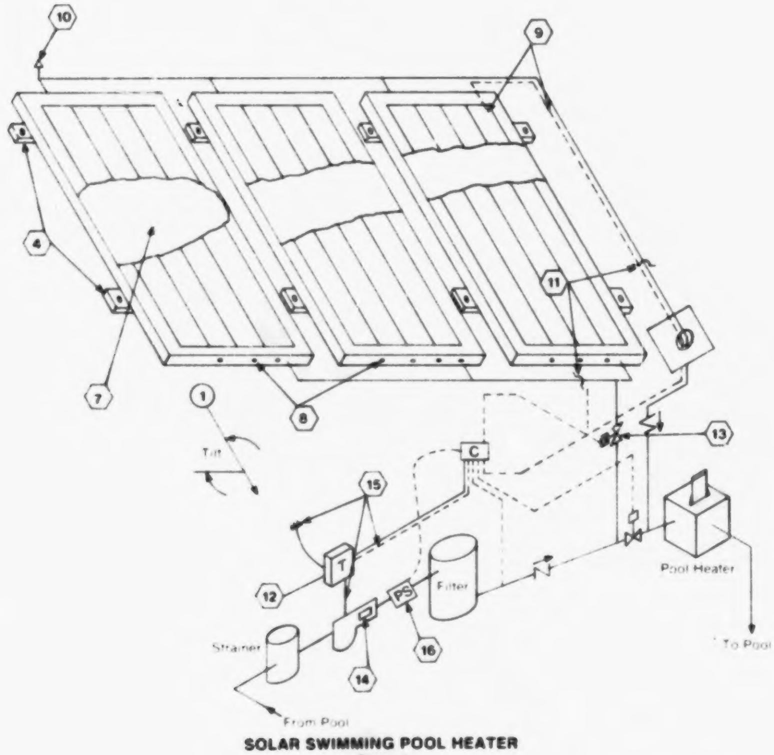
SOLAR SWIMMING POOL HEATER
Unglazed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SOLAR SWIMMING POOL HEATER
Glazed

2.6.4 Solar Swimming Pool Heating Systems

Unglazed Collectors

> Note: Although the RCS Model Audit does not include pool heating applications with unglazed solar collectors, the following section does present an inspection procedure for this type of panel. The section is included as a service to solar inspectors and installers because unglazed pool heating systems have become so commonplace.

1. **Observe the orientation of the collectors to ensure that they face within 90° of true south. Observe the tilt angle to ensure that it is less than local latitude (see Figs. 2-74, 2-75).**

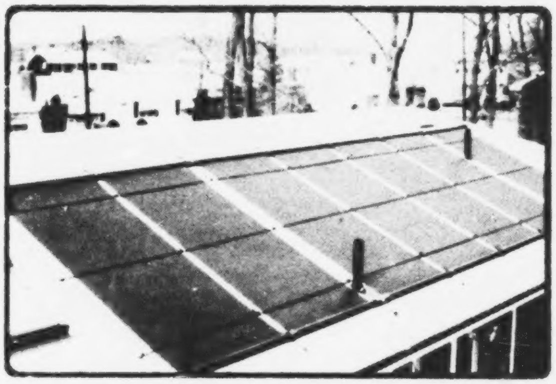

Figure 2-74. Unglazed Solar Swimming Pool Collectors

Figure 2-75. Orientation of Collectors

See discussion of SDHW Checkpoint #1.

> Note: For discussion of solar angles relating to pool systems, refer to Section 2.5.2.

2. **Observe the sun's path relative to the collectors to ensure that the collection area is not shaded from 9:00 am to 3:00 pm during the time of year when the pool is being used.**

See discussion of SDHW Checkpoint #2.

3. **Inspect the anchorage of the collectors to the roof. Ensure that lag bolts and wind straps have been installed at proper intervals as per manufacturer's specifications (See Fig. 2-76).**

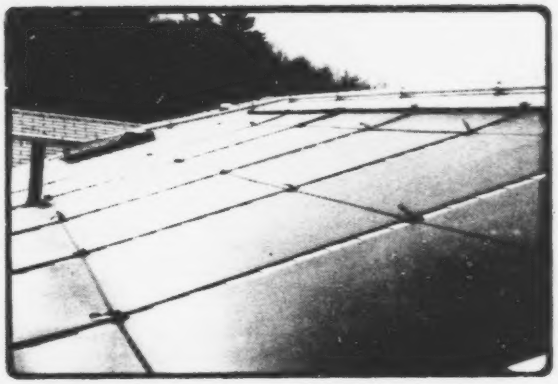

Figure 2-76. Anchorage of Collectors to Roof

Background for Inspection

Most unglazed solar swimming pool collectors popular today are constructed of black polypropylene. Despite their large surface areas (often 40 ft^2), these collectors are generally light (less than 20 lb each) and pliable. For these reasons, the manufacturers provide specific means to secure the collectors to the roof so that wind will not be a problem. Unlike glazed collectors with cases, unglazed panels are usually mounted directly onto the roof surface. The common fastening technique involves the use of three or four carefully spaced horizontal straps across the face of each collector. These straps are attached to the roof with specially designed fasteners, lagged into the roof and liberally coated with polysulfide sealant. Additionial tie-down straps or clamps are widely used on the top and bottom manifolds of each collector as well.

Special Tools

None.

Inspection Procedure

Visually inspect collector anchorage to ensure that it is consistent with the manufacturer's specifications.

4. **Ensure that all collector tie-downs adequately allow for thermal expansion and contraction as per manufacturer's specifications (See Fig. 2-77).**

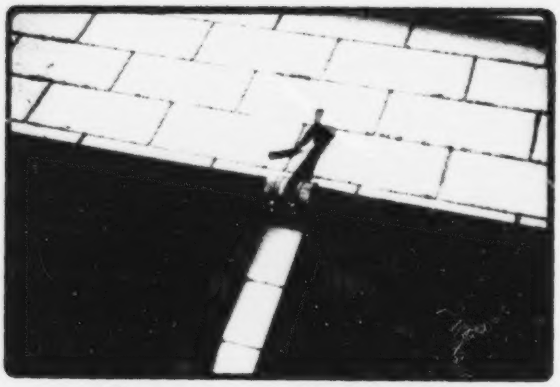

Figure 2-77. Collector Tie-Downs

Background for Inspection

A critical consideration in the proper mounting of unglazed pool collectors is the allowance for expansion and contraction. As the collectors have large fully "wetted" surface areas, there is potential for expansion/contraction up to several inches when pool water is alternately supplied and not supplied, especially since ambient air conditions can vary dramatically.

In order to handle this problem, all tie-downs and clamps must be flexible and strong. There are a number of different successful approaches. Some manufacturers use clamps which are slotted, allowing for movement; others use pliable strap tie-downs. Whatever technique is used, it is critical that the installer allow the precise instructions of the supplier.

Special Tools Required

None.

Inspection Procedure

Visually inspect collector mounting flexibility, ensuring that it is consistent with the manufacturer's specifications.

5. **If a roof rack has been used, ensure that it has been anchored to the roof using blocking, spanner mounting, or direct lagging into rafters and has not caused leaks (See Fig. 2-78).**

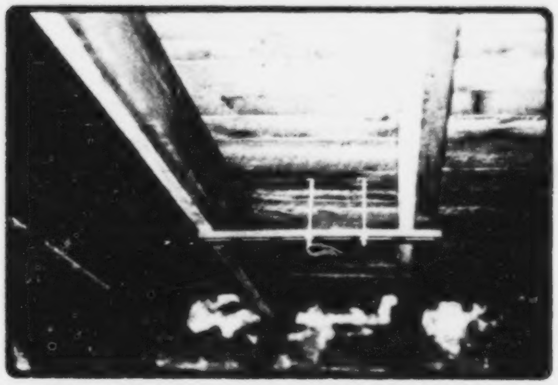

Figure 2-78. Spanner Mounting-Bottomside

See discussion of SDHW Checkpoint #5.

Note: Roof racks are not widely used with unglazed pool systems since this form of solar collection is relatively tolerant of a wide range of tilt and azimuth angles. However, when racks are constructed, the same structural and mounting considerations typical of water and space heaters come into play. Refer to Inspection Point 5, SDHW.

6. **Observe the piping to and from the collectors and the collector's interconnections to ensure that there are no leaks (See Fig. 2-79).**

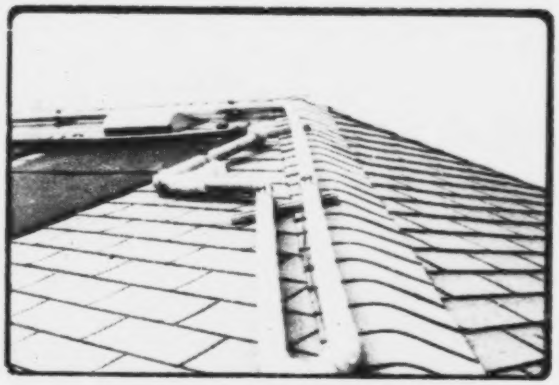

Figure 2-79. Piping to and from Collector

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Background Information

It is important that unglazed pool systems be leak-free, as their thermal efficiency relies on moving a large volume of water through the system. A small leak can worsen quickly.

Special Tools Required

None.

Inspection Procedure

Since most unglazed collector systems use uninsulated PVC piping, the test procedure is straightforward. After turning the controller (and therefore the pump) to the "on" position to ensure circulation, each fitting and interconnection can be watched for any seepage. Generally speaking, a prior leak will be detectable by slight discoloration of the adjacent roof or wall surface.

7. **Ensure that all piping is properly pitched to allow the system to drain down completely (See Fig. 2-80).**

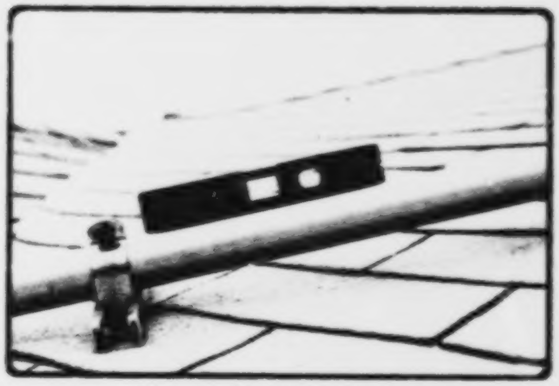

Figure 2-80. Pitch of Piping

See discussion of SDHW Checkpoint #23.

8. **Ensure that a vacuum breaker has been installed at the high point of the collector array(s) (See Fig. 2-81).**

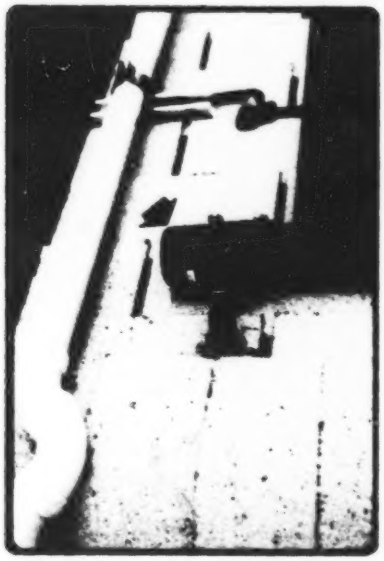

Figure 2-81. Vacuum Breaker

Background for Inspection

As unglazed pool systems rely on draining all water back to the pool during times of no collection, vacuum breakers must be installed at the high point of each collector array.

Special Tools Required

None.

Inspection Procedure

The vacuum breakers used in this application are typically different from normal breakers and vary in design from manufacturer to manufacturer. Usually, however, they are easily identifiable by a label. Their proper operation is verified by allowing the collectors to drain down and listening for the rush of air through each vacuum relief.

9. **Inspect the pipe support to ensure that they satisfy local code (see Fig. 2-82).**

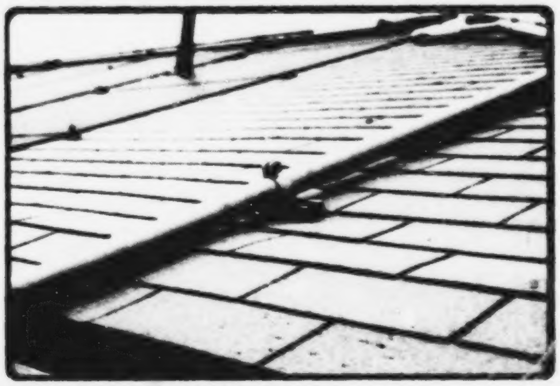

Figure 2-82. Pipe Support

See discussion of SDHW Checkpoint #15.

10. **Ensure that the collector sensor is properly mounted near the collectors, is unshaded, and is sensing the same thermal conditions as the collectors (See Fig. 2-83).**

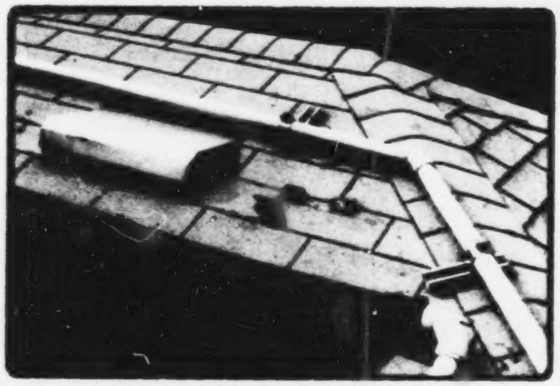

Figure 2-83. Collector Sensor

Background for Inspection

Unlike sensors in glazed collector systems, unglazed pool system sensors are purposely placed on the roof fully exposed to ambient conditions. The sensor should be placed somewhere near the middle of the collector array and care must be taken that it is not shaded whenever the bulk of the array itself is receiving insolation. The sensor wire splices must be made carefully. Many installers use wire nuts filled with silicone sealant to ensure long-term, moisture-free contact.

Special Tools Required

None.

Inspection Procedure

Visually inspect for proper sensor mounting.

11. **Ensure that the pool sensor is properly mounted for the pipe material type and is properly sensing pool temperature (Normally in plastic piping system the sensor should be in a "T-Well.") (See Fig. 2-84).**

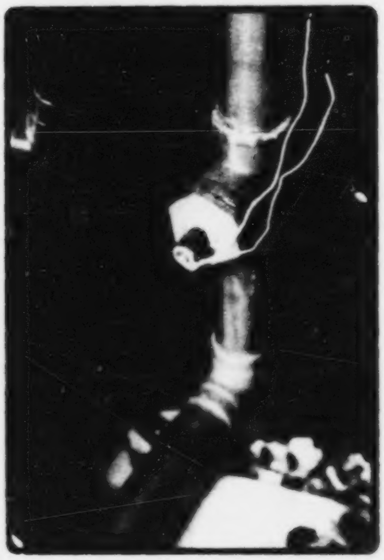

Figure 2-84. Pool Sensor

Background for Inspection

Whereas the collector sensor must read dry roof conditions, the pool sensor must measure the temperature of the pool water itself. An immersion sensor is therefore used. The normal placement for the sensor is near the pump in a T-well, sensing the temperature of the water being pumped through the filter loop.

Special Tools Required

None.

Inspection Procedure

Visually inspect for proper sensor mounting.

12. **Ensure that additional solenoid valves are provided on the pool collector feed lines, to prevent collector flooding during periods of inadequate solar insolation (See Fig. 2-85).**

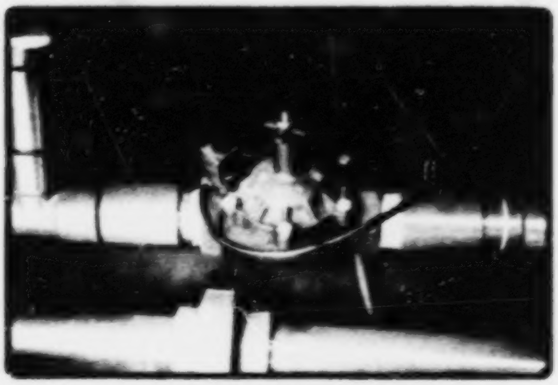

Figure 2-85. Solenoid Valve

Background Information

As with any type of solar collection loop, care must be taken in the installation of pool systems to prevent thermosyphoning. The condition can occur when the storage (the pool itself) is warmer than the collection area (at night, for example). The pool water can theoretically begin to circulate, dissipating any heat that may have been gained during the day. A preventive device must be installed in the collector feed line. The most widely used technique is the installation of a "normally closed" solenoid valve which will open only when the controller calls for circulation through the collectors.

Special Tools Required

None.

Inspection Procedure

Visually inspect for a valve which will prevent thermosyphoning. It is generally installed close to the tee of the filter/pump loop.

13. **Ensure that sufficient pump capacity is provided to maintain adequate flow to the collectors (See Fig. 2-86).**

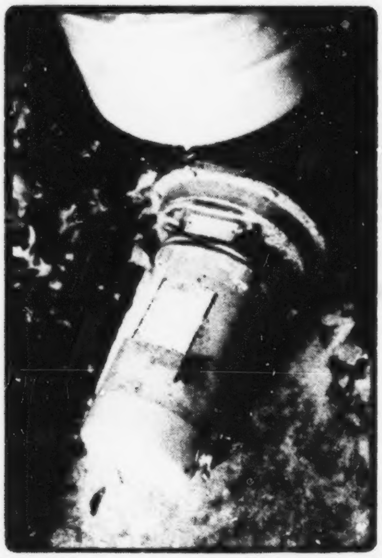

Figure 2-86. Pump with Pump Capacity Label

Background for Inspection

An important consideration is that the pool pump have high enough capacity to serve its own loop and also maintain a sufficiently high rate of flow through the collectors to assure proper heat transfer. As a rule of thumb, 1/2-hp circulation pumps often found on swimming pool applications will generally not be adequate, but 3/4-hp pumps in good condition are usually sufficient for systems on 15,000-gal pools.

Special Tools Required

None.

Inspection Procedure

Visually inspect the pump label to ensure that it meets with the solar manufacturer's specifications.

14. **Ensure that 120V wiring to the controller and/or pump is contained within rigid or flexible conduit, or per local code, and that the power source receptacle is grounded (See Fig. 2-87).**

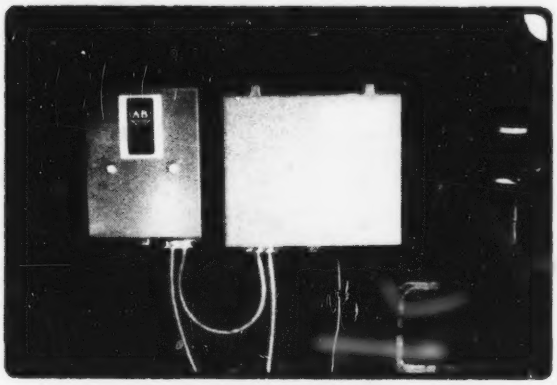

Figure 2-87. Electrical Wiring in Conduit

See discussion of SDHW Checkpoint #28.

Glazed Collectors

> Note: For any pool systems with outdoor electrical components, ensure that local codes for outdoor wiring are followed.

1. **Observe the orientation of the collectors to ensure that they face within 90° of true south. Observe the tilt angle to ensure that it is less than local latitude.**

See discussion of Unglazed Solar Swimming Pool Heaters Checkpoint #1.

2. **Observe the sun's path relative to the collectors to ensure that the collection area is not shaded from 9:00 am to 3:00 pm during the time of year when the pool is being used.**

See discussion of SDHW Checkpoint #2.

3. **Verify that the collectors have been tested according to ASHRAE 93-77. A label may be attached to the collectors containing this information. If not, the model name and/or model number on the collectors will help in a verification investigation.**

See discussion of SDHW Checkpoint #10.

4. **Inspect the anchorage of the rack or the individual collector standoffs to the roof to ensure that blocking, spanner mounting or direct lagging into rafters has been used and has not caused leaks in the roof.**

See discussion of SDHW Checkpoint #5.

5. **Ensure that any additional wind, snow, or seismic loadings of the collectors do not cause the building to violate local codes.**

See discussion of SDHW Checkpoint #6.

6. **Ensure that any home entrances are protected from snow slides in areas with snow loads of 20 lb/ft^2. In areas where snow loads are greater than 20 lb/ft^2 (check with local codes), the placement of collectors directly over entrances should be avoided. However, if there is no option, a strong deflector should be attached in a structurally sound manner.**

See discussion SDHW Checkpoint #7.

7. **Ensure that collectors are safety-glazed or otherwise protected in ground or wall mounts with glazings less than 45° and within 6 ft of the ground.**

See discussion SDHW Checkpoint #9.

8. **Ensure that the collectors are undamaged and placed for proper flow and drainage. Weep holes must face the bottom.**

See discussion of SDHW Checkpoint #11.

9. **Inspect for weather protection of all outdoor sensors, sensor wire and wire splices. Ensure that sensors are not mounted on the outside of the case or on the roof.**

See discussion of SDHW Checkpoint #12.

10. **Ensure that a vacuum breaker has been installed at a high point of the collector piping for a draindown system.**

See discussion of Unglazed Solar Swimming Pool Heaters Checkpoint #8.

11. **Inspect the pipe supports to ensure that they satisfy local codes. Normally, vertical pipe supports should be 10 ft on centers; horizontal supports should be 6 ft on centers.**

See discussion of SDHW Checkpoint #15.

12. **Where a pool pump timer is used, ensure that the timer and the solar collector controller are electrically interlocked.**

Background for Inspection

In systems in which a pool pump on a timer is the same pump which is utilized to supply the solar collectors, it is important that the timer and the controller are interconnected so that when the timer shuts off, the water in the collectors will automatically drain down to the pool.

Special Tools Required

None.

Inspection Procedure

The timer/controller connection is checked by turning the timer to the "off" position during a time of favorable solar conditions and observing whether or not the water circulating through the panels drains out.

13. **Ensure that additional solenoid valves are provided on the pool collector feed lines to prevent collector flooding during periods of inadequate solar insolation.**

See discussion of Unglazed Solar Swimming Pool Heaters Checkpoint #12.

14. **Ensure that sufficient pump capacity is provided to maintain adequate flow to the collectors.**

See discussion of Unglazed Solar Swimming Pool Heaters Checkpoint #13.

15. **Ensure that 120V wiring to the controller and/or pump is contained within rigid or flexible conduit or per local code, and that the power source receptacle is grounded.**

See discussion of SDHW Checkpoint #28.

16. **Ensure that the pool sensor is properly mounted for the pipe material type and is properly sensing pool temperature. Normally in a plastic piping system the sensor should be in a "T-Well."**

See discussion of Unglazed Solar Swimming Pool Heaters Checkpoint #11.

2.7 REVIEW QUESTIONS

Basic Components

1. Why are unglazed flat-plate collectors often used for pool heating?
2. Why are glazed flat-plate collectors more popular for domestic water heating than concentrating or evacuated-tube collectors?
3. What are four principal components of a glazed flat-plate collector?
4. Why is black chrome absorber plating more popular for domestic water heating than double glazing?
5. What is stagnation?
6. What is reverse-return piping and why is it important?
7. In what solar systems may PVC piping be used?
8. Which of the following solar water heating systems use pressurized storage tanks:

   draindown; drainback; closed loop?
9. Why do closed loop systems require less pumping power than drainback systems?
10. In what solar systems must a bronze or stainless pump be used?
11. What service considerations do solar antifreeze solutions usually have?
12. Why is water a popular solar storage medium?
13. Why does rock storage require greater volume than water storage?
14. Is it always true that as a flat-plate collector temperature increases, efficiency decreases?
15. What are typical on/off temperature differentials for solar water heating controllers?

Solar Domestic Hot Water Systems

1. What are the preferred tilt and azimuth angles for solar water heaters?
2. Define Btu.
3. What is a typical domestic hot water delivery temperature?
4. How much hot water does the average person use at home every day?
5. Why are solar systems not ordinarily sized to provide a 100% solar contribution?

6. Explain the importance of temperature stratification in a solar water heating storage tank with an immersed coil?

7. Why are by-pass interconnections often used with double-tank solar water heating systems?

8. Name four conservation measures which should be considered along with the installation of a solar water heater.

9. If a family uses 75 gal of hot water per day, their incoming water temperature average is 55°, and the delivery temperature is 135°, how many net Btu per year are required for water heating?

10. Which of the following systems require a pressure relief valve on the solar loop:

    closed loop; drainback; draindown ?

Active Solar Space Heating Systems

1. What are the preferred tilt and azimuth angles for solar space heating?

2. Why are solar space heating systems more difficult to retrofit than solar water heaters?

3. What is F-Chart?

4. Name three common methods of delivering solar space heat.

5. What is a water-to-air heat exchanger?

6. Why is air distribution of solar-derived heat more widely used than hydronic distribution?

7. What are a few of the considerations for using existing residential baseboard for delivering solar heat?

8. What is a fan coil unit?

9. Describe the function of a two-stage thermostat.

10. What are the advantages of adding a solar water heater to a solar space heating system whenever possible?

Solar Swimming Pool Heating Systems

1. What are the preferred tilt and azimuth angles for solar swimming pool heating systems?

2. Why are solar pool heaters relatively simple technically?

3. Describe a sizing technique for solar swimming pool collectors.

4. What considerations should be given to pool pumps when adding solar systems?

Inspector's Checklists and Discussion

1. What is an Abney Level?
2. What is the solar significance of March 21?
3. What is an isogonic correction?
4. Why must collectors be mounted on standoffs?
5. Name three acceptable rack attachment methods.
6. What is a range of weights of typical solar collectors?
7. What is ASHRAE 93-77?
8. What is a weep hole?
9. What are minimum pipe and storage tank insulation R-values?
10. Why should check valves be installed in closed-loop solar systems?
11. Why must tempering valves be installed on solar water heaters?
12. Why do certain local codes require backflow preventers on solar systems?
13. What are the commonly accepted intervals for hanging copper pipe?
14. What is a fill/drain assembly?
15. What consideration must be given to the installation of relief valves?
16. Describe the considerations for all solar water heating system wiring: sensors, controllers, circulators, backup elements.

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CHAPTER 3

ASSURANCE/TESTING AND TROUBLESHOOTING

3.1 OVERVIEW

The following are ways for inspectors and installers of active solar systems to assure that some measure of performance is being derived from a given system.

Because of their relative simplicity, it is possible to be relatively specific about solar water heaters and pool systems. However, with space heating systems, only a very few general comments are possible. With space heating it is necessary to understand the design and goals of the specific system, particularly in relation to the heat distribution system.

In this section, it is assumed that the inspector testing the system will be equipped only with a compass, an inclinometer, a tape measure, and a contact thermometer. To test an active system thoroughly would involve far more equipment. Multitesters to compare resistance with control operation, pH testers and refractometers to analyze heat transfer fluids, complete manufacturer and designer schematics, and installation instructions would all be required.

In any case, any consideration of testing and troubleshooting immediately points to the value of installing proper thermometers and pressure gauges in all solar systems. Obviously, the simplest test of any solar system—a test that many homeowners like to do daily—is to monitor the temperature on any solar storage tank without auxiliary backup heating. In such a water heater, for example, the difference between the tank top temperature and the incoming water temperatures would be fully attributable to solar collection.

3.2 SOLAR DOMESTIC HOT WATER SYSTEMS

3.2.1 Closed-Loop Systems

- **Check System Pressure**

  As indicated in the checklists, it is necessary for all closed-loop systems to have a pressure gauge on the loop. The loop usually must hold pressure in a range of 15 to 40 psi for proper heat transfer to take place.

  Antifreeze solutions used in solar system loops have very little surface tension and can leak easily. A leak is immediately detectable when loop pressure drops. If the system has been tagged, and original fill pressure was noted by the installer, a drop of more than 10 psi would ordinarily indicate a problem.

- **Check the Controller**

  Many controllers feature a running light that will operate when the controller calls for the pump to run. If solar conditions call for system operation, ensure that the running light is on.

Most controllers have a three-way mode switch: on, off, and automatic. This switch is often placed inside the controller box so as to be tamper-proof. Ensure that the switch is in the automatic mode, which means that the controller can respond to the varying impulses from the collector and tank sensors.

- **Check the Circulator**

  If solar conditions call for system operation, ensure that the circulator pump is operating. This may be difficult as the circulators are usually small (1/25 hp) and quiet. If operating, circulators will typically feel very hot to the touch, since they are lubricated by the solar fluid itself.

  Ensure that the circulator is running quietly, without any bearing or metallic noises. Listen, too, for gurgling noises indicating that the system has entrapped air that would decrease thermal performance. All entrapped air should be purged at once to avoid an "air-lock" situation.

- **Check Solar Loop Temperatures**

  Many solar installers place thermometers on both the supply and return sides of the solar loop. Many factors affect what the temperatures might be at any given time. However, when the system is operating properly, the return from the collectors to the heat exchanger should always be hotter than the supply to the collectors from the heat exchanger. An average temperature differential for a solar water heater across the heat exchanger might be in the range of 5° to 15°F.

  If the system does not have built-in thermometers, the same test may be performed by taking readings with a contact thermometer. Care must be taken, however, to make sure that the probe has pierced the insulation completely and is held on the piping long enough to achieve accurate readings.

3.2.2 Drainback Systems

- If a water level sight gauge has been installed in the system, shut the system down allowing the water to drain back to the storage tank. Ensure that the water level is adequate.
- Check the controller as with a closed-loop system.
- Check the pump for operation (as with a circulator for a closed-loop system). It will be easier to tell if a drainback pump is operating because of its larger size and horsepower.
- Check loop temperatures as with a closed-loop system.

3.2.3 Draindown Systems

- Check the automatic draindown mode by turning the controller switch into the off position and ensuring that all the water drains from the system.
- Check the controller as with closed-loop and drainback systems.
- Check the pump as with closed-loop and drainback systems.
- Check loop temperatures as with closed-loop and drainback systems.

3.2.4 Thermosyphon Systems

Because of their technical simplicity, the thermal performance of thermosyphon systems is difficult to test. The most important measure is to ensure that the collectors are providing heat transfer by checking differential temperatures between the pipes to and from the collectors. A 10°-temperature differential typically indicates proper functioning.

3.3 SPACE HEATING SYSTEMS

3.3.1 Water Storage/Air Distribution

- Check solar loop for performance using appropriate system (closed loop, drainback, or draindown) recommendations from previous section.
- If storage temperatures and design conditions allow solar distribution system operation, ensure that circulation to the water-to-air solar heat exchanger is taking place.
- If operating conditions do not exist, cycle the furnace blower on and off to ensure that the furnace blower and the controller are interlocked. The pumps and valves should operate when the existing furnace blower is operating.

3.3.2 Water Storage/Forced Hot Water Distribution

- Check solar loop for performance using appropriate system (closed loop, drainback, or draindown) recommendations from previous section.
- If storage temperatures and design conditions allow, ensure that heat delivery is operating in the solar mode without assistance from the boiler.

3.3.3 Water Storage/Parallel Forced Hot Water Distribution

- Check solar loop for performance using appropriate system (closed loop, drainback, or draindown) recommendations from previous section.
- If storage temperatures and design conditions allow solar distribution system operation, ensure that heat is being delivered to the finned-tube or fan-coil units.

3.4 SOLAR SWIMMING POOL HEATING SYSTEMS

1.) Check that the controller switch is in the automatic mode.

2.) If weather conditions and the pool temperature permit solar collection, check that circulation through the solar collectors is taking place.

3.) Check the temperature (by hand or by thermometer) and compare the collector supply and return lines to be sure that heat is being collected.

4.) If the system is operating, check (by hand or thermometer) the temperature at various spots on each of the unglazed absorbers. An even, cool temperature across the entire array assures that properly balanced flow and heat transfer are taking place.

5.) If the system is operating, turn the controller to the off position to ensure that the water in the panels can drain completely back to the pool.

6.) After step 5 is completed, turn the controller back to automatic. If the same weather conditions exist so that the system shuts off, ensure that all water drains completely back to the pool.

7.) If the system is not operating, turn the controller to manual or on to begin circulation. Then check for flow as in step 4.

3.5 TROUBLESHOOTING

The following section includes troubleshooting checklists for thermosyphon, recirculation, draindown, drainback, antifreeze closed-loop, and air solar domestic hot water systems. Although most of the checkpoints are outside the scope of a typical system performance test, the information is valuable to installers and inspectors who are trying to understand why a particular system might not be working properly and how it should be corrected.

The checklists were compiled by the Argonne National Laboratory and are presented in the document entitled Interim Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems (September 1980). It is important to remember that the guidelines are generic in nature. The first step in diagnosing any solar system problem should be to refer to whatever specific troubleshooting guidelines the system manufacturer may offer.

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Table 3-1. Troubleshooting Guidelines for Thermosyphon Systems

Problem	Components	Possible Causes	Corrective Action
System does not start	Piping	Pipe blocked.	Remove blockage to the water flow.
System leaks	Pipe joints	1. Thermal expansion and contraction. 2. Joint improperly made.	1. Provide flexibility and reassemble. 2. Reassemble leaky joints.
	Hose connection	Clamp does not hold tightly.	Tighten up the hose clamp. Replace clamp or hose
	Relief valve	1. Improper pressure setting. 2. Defective component. 3. Designer did not provide enough space for the thermal expansion in the storage tank.	1. Check pressure setting and correct. 2. Replace. 3. Drain excessive water out of the storage tank.
No hot water	Make-up water shut-off valve	Valve closed.	Open valve.
	Electric heater	No power to electric heater.	Check overload protection and correct.
	Auxiliary heater thermostat	1. Thermostat defective. 2. Bad contacts.	1. Replace. 2. Correct.
	Auxiliary heater sensor	1. Sensor out of calibration. 2. Sensor defective.	1. Recalibrate. 2. Replace.
	Mixing valve	1. Valve defective. 2. Sensor defective. 3. Leak in capillary tubing.	1. Replace. 2. Replace. 3. Replace
Hot water temperature not high enough	Auxiliary heater thermostat and/or overheat protection thermostat	1. Thermostat setting too low. 2. Thermostat out of calibration.	1. Set thermostat higher. 2. Recalibrate or replace thermostat.
	Auxiliary heater	Undersized heater for hot water demand.	Replace when heater fails.
	Safety switch	Set too low.	Check and reset.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too low. 3. Valve spring too weak.	1. Recalibrate. 2. Reset. 3. Replace.
Water temperature too high	Hot water temperature	1. Thermostat setting too high. 2. Thermostat out of calibration. 3. Bad contacts.	1. Reset. 2. Recalibrate. 3. Correct.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too high.	1. Recalibrate. 2. Reset.
	Sensor	Out of calibration	Recalibrate.
Poor solar energy collection	Collector array	1. Collector area undersized. 2. Collectors shaded. 3. Flow rate too high or too low. 4. Heat transfer surface covered with scale deposits. 5. Leaks.	1. Install more collector area. 2. Remove obstacle or install collectors in more appropriate location 3. Rebalance flow. 4. Flush collector loop. 5. Repair
	Piping	1. Insufficient insulation. 2. Improper weather protection. 3. Insulation damaged. 4. Undersized piping between storage tank and collector. 5. Piping partially blocked.	1. Add additional insulation. 2. Provide proper weather protection. 3. Repair. 4. Install adequate piping. 5. Flush piping runs.

Source: Argonne National Laboratory. Interim Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems, ANL/SDP-9; Solar/0907-80/70

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Table 3-2. Troubleshooting Guidelines for Recirculation Systems

Problem	Components	Possible Causes	Corrective Action
System does not start	Power supply	1. Tripped on overload.	1. Determine cause and replace fuse or breaker
		2. Open circuit breaker.	2. Check and close.
		3. Defective transformer.	3. Replace.
		4. Line voltage fluctuating.	4. Inform power company.
		5. Brownout.	5. Provide brownout protective device and inform power company
		6. Control switch on "off" position.	6. Turn to "auto" position.
	Thermostat	1. High and low temperature differential set points too high.	1. Reset according to specifications or results obtained during system start-up and testing.
		2. Defective component.	2. Replace thermostat.
		3. Loose contacts.	3. Tighten wires.
		4. Themostat is out of calibration.	4. Recalibrate.
	Sensor(s)	1. Defective.	1. Replace.
		2. Improper installation.	2. Reinstall.
		3. Defective control cable.	3. Replace.
		4. Sensor out of calibration.	4. Recalibrate.
	Pump	1. Motor failure.	1. Check brush holders, throw-out mechanisms, centrifugal switches, or other mechanical components that may be loose, worn, dirty, or gummy. Replace worn components and reassemble.
		2. Overload protection switch shuts down pump motor.	2. Determine cause of overloading; check if balancing valve is in proper position.
		3. Defective shaft, impeller, or coupling.	3. Replace.
		4. Defective bearings.	4. Replace
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
System starts but cycles	Thermostat	High and low temperature differential set points are too close together.	Reset according to specification or results obtained during system start-up and testing.
		Freeze protection setting too high.	Reset thermostat.
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
Pump runs but water does not flow to collectors	Supply valve closed	1. Actuator defective.	1. Replace actuator.
		2. No power to actuator.	2. Check wiring.
		3. Valve sticks.	3. Cycle valve by jumping control system or replace actuator.
	Pump impeller	Impeller broken or separated from shaft.	Replace impeller and/or shaft assembly.
	Blocked liquid flow passage	Pipe damaged.	Replace damaged section.
System runs continuously	Thermostat	1. Low temperature differential set point set too low.	1. Reset according to specifications or results obtained during start-up.
		2. Defective component.	2. Replace thermostat.
		3. Thermostat is out of calibration.	3. Recalibrate.
	Freeze protection function	1. Set point drifted.	1. Reset.
		2. Defective components or welded.	2. Replace.
		3. Loose contacts.	3. Tighten wires.
		4. Thermostat is out of calibration.	4. Recalibrate
	Sensor(s)	1. Sensor(s) out of calibration.	2. Calibrate.
		2. Defective sensor.	2. Replace.
		3. Improper installation.	3. Reinstall.
	Control circuitry	Bad contacts.	Check and correct.

Table 3-2. Troubleshooting Guidelines for Recirculation Systems (Continued)

Problem	Components	Possible Causes	Corrective Action
No hot water	Make-up water shut-off valve	Valve closed.	Open valve.
	Heater failed to actuate	1. Electric heater, single tank systems. a. No power to electric heater (single-tank system only). 2. Gas heater (double-tank systems only). a. Failure to ignite (gas off). b. Safety switch malfunctioning. c. Defective thermocouple and/or automatic pilot valve. d. Pilot won't stay lit. 1 Too much primary air. 2 Dirt in pilot orifice. 3 Pilot valve defective. 4 Loose thermocouple connection. 5 Defective thermocouple. 6 Improper pilot gas adjustment. 3. Both systems a. Thermostat defective. b. Bad contacts	 a. Check overload protection, correct. a. Open manual valve. b. Check and replace. c. Check and replace. d. 1 Adjust pilot shutter. 2 Open orifice. 3 Replace. 4 Tighten. 5 Replace. 6 Adjust. a. Replace. b. Correct.
	Temperature modulating valve	1. Valve defective. 2. Sensor defective. 3. Leak in capillary tubing.	1. Replace. 2. Replace. 3. Replace.
Hot water temperature not high enough	Hot water thermostat	1. Thermostat setting too low. 2. Thermostat out of calibration.	1. Set thermostat higher. 2. Recalibrate or replace thermostat.
	Auxiliary heater	Undersized heater for hot water demand	Replace when heater fails.
	Safety switch	Set too low.	Check and reset.
	Burner double-tank system only	1. Burner clogged. 2. Undersized burner orifice.	1. Clean. 2. Provide correctly sized orifice.
System leaks	Pipe joints	1. Thermal expansion and contraction. 2. Joint improperly made.	1. Provide flexibility and reassemble. 2. Reassemble leaky joint.
	Hose connection	Clamp does not hold tight.	Tighten up the hose clamp. Replace clamp or hose.
	Relief valve	1. Improper pressure setting. 2. Defective component.	1. Check pressure setting and correct. 2. Replace.
Poor solar energy collection	Collector array	1. Undersized collector area. 2. Collectors shaded. 3. Flow rate too high or too low. 4. Heat transfer surface covered with scale deposits. 5. Leaks.	1. Install more collector area. 2. Remove obstacle or install collectors in more appropriate location 3. Rebalance flow. 4. Flush collector loop. 5. Repair.
	Piping	1. Insufficient insulation. 2. Improper weather protection. 3. Insulation damaged	1. Add additional insulation. 2. Provide proper weather protection. 3. Repair.
System noisy when operating	Pump cavitation	1. Restricted pump suction line. 2. Air in the system.	1. Remove restrictions. 2. Manually vent the system if automatic air vents are not adequate.
	Pump bearings	1. Bearing worn. 2. Bearing damaged due to improper alignment.	1. Replace. 2. Properly align pump and motor shaft.
	Piping	1. Air locked in the piping. 2. Piping vibrates.	1. Air vent the system. 2. Provide adequate pipe support.
	Air vents	Residual air in system or air leak.	Purge air from system.

Table 3-2. Troubleshooting Guidelines for Recirculation Systems (Concluded)

Problem	Components	Possible Causes	Corrective Action
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too low. 3. Valve spring too weak.	1. Recalibrate. 2. Reset. 3. Replace.
Water temperature too high	Hot water temperature	1. Thermostat setting too high. 2. Thermostat out of calibration 3. Bad contacts.	1. Reset. 2. Recalibrate. 3. Correct.
	Sensor	Out of calibration.	Recalibrate or replace
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too high.	1. Recalibrate. 2. Reset.

Source: Argonne National Laboratory. Interim Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems, ANL/SDP-9; Solar/0907-80/70

Table 3-3. Troubleshooting Guidelines for Draindown Systems

Problem	Components	Possible Causes	Corrective Action
System does not start	Power supply	1. Tripped on overload.	1. Determine cause and replace fuse or breaker.
		2. Open circuit breaker.	2. Check and close.
		3. Defective transformer.	3. Replace.
		4. Line voltage fluctuating.	4. Inform power company.
		5. Brownout.	5. Provide brownout protective device and inform power company.
		6. Control switch on "off" position.	6. Turn to "auto" position.
	Thermostat	1. High and low temperature differential set points too high.	1. Reset according to specifications and/or results obtained during system start-up and testing.
		2. Defective component.	2. Replace thermostat.
		3. Loose contacts.	3. Tighten wires.
		4. Thermostat is out of calibration.	4. Recalibrate.
	Sensor	1. Defective.	1. Replace.
		2. Improper installation.	2. Reinstall.
		3. Defective control cable.	3. Replace.
		4. Sensor out of calibration.	4. Recalibrate.
	Pump	1. Motor failure.	1. Check brush holders, throw-out mechanisms, centrifugal switches, or other mechanical components that may be loose, worn, dirty, or gummy. Replace worn components and reassemble.
		2. Overload protection switch shuts down pump motor.	2. Determine cause of overloading; check if balancing valve is in proper position.
		3. Defective shaft, impeller, or coupling.	3. Replace.
		4. Defective bearings.	4. Replace.
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
	Control circuitry	1. Bad contacts.	1. Check and correct.
System does not drain	Freeze protection thermostat	1. Set point drifted.	1. Reset.
		2. Defective components.	2. Replace.
		3. Loose contacts.	3. Tighten wires.
		4. Thermostat is out of calibration.	4. Recalibrate.
	Sensor(s)	1. Sensor(s) out of calibration.	1. Calibrate.
		2. Defective sensor.	2. Replace.
		3. Improper installation.	3. Reinstall.
	Vacuum breaker	1. Does not open	1. Replace.
		2. Frozen.	2. Add heat tape.
	Drain-down valve closed	1. Actuator defective.	1. Replace actuator.
		2. No power to actuator.	2. Check control wiring.
		3. Valve sticks.	3. Cycle valve by jumping control system or replace actuator.
System drains continually	Drain-down valve open	1. Actuator defective	1. Replace actuator.
		2. No power to actuator.	2. Check wiring.
		3. Valve sticks.	3. Cycle valve by jumping control system or replace actuator.
	Check-valve	Check-valve leaks.	Isolate valve and replace.
	Freeze protection thermostat	1. Set point drifted.	1. Reset.
		2. Defective components.	2. Replace.
		3. Loose contacts.	3. Tighten wires.
		4. Thermostat is out of calibration.	4. Calibrate.
	Sensor(s)	1. Sensor(s) out of calibration.	1. Calibrate.
		2. Defective sensor.	2. Replace.
		3. Sensor improperly installed.	3. Reinstall.

Table 3-3. Troubleshooting Guidelines for Draindown Systems (Continued)

Problem	Components	Possible Causes	Corrective Action
System starts but cycles	Thermostat	High and low temperature differential set points are too close together.	Reset according to specification and/or results obtained during system start-up and testing
	Time delay relay	Time delay "times out" too soon (freeze protection sensor does not heat up in time).	Increase time delay relay setting.
	Control circuitry	1. Circuit continuity lost. 2. Bad contacts.	1. Check and repair. 2. Check and correct.
Pump runs but water does not flow to collectors	Supply valve closed	1. Actuator defective. 2. No power to actuator. 3. Valve sticks.	1. Replace actuator. 2. Check wiring. 3. Cycle valve by jumping control system or replace actuator.
	Draindown valve open	1. Actuator defective. 2. No power to actuator. 3. Valve sticks.	1. Replace actuator. 2. Check wiring. 3. Cycle valve by jumping control or replace actuator.
	System air-locked	Air vent(s) jammed closed.	Replace vent(s).
	Pump impeller	Impeller broken or separated from shaft.	Replace impeller and/or shaft assembly.
	Blocked liquid flow passage	Pipe damaged.	Replace damaged section.
System runs continuously	Thermostat	1. Low temperature differential set point set too low. 2. Defective component. 3. Thermostat is out of calibration.	1. Reset according to specifications or results obtained during start-up. 2. Replace thermostat. 3. Recalibrate.
	Sensor(s)	1. Defective sensor(s) 2. Sensor(s) is out of calibration	1. Replace. 2. Recalibrate.
No hot water	Make-up water shut-off valve	Valve closed.	Open valve.
	Heater failed to actuate	1. Electric heater (single-tank systems). a. No power to electric heater (single-tank systems only).	a. Check overload protection and correct.
		2. Gas heater (double-tank systems only). a. Failure to ignite (gas off). b. Safety switch malfunctioning. c. Defective thermocouple and/or automatic pilot valve. d. Pilot won't stay lit. 1 Too much primary air. 2 Dirt in pilot orifice. 3 Pilot valve defective. 4 Loose thermocouple connection. 5 Defective thermocouple. 6 Improper pilot gas adjustment.	a. Open manual valve. b. Check and replace. c. Check and replace. d. 1 Adjust pilot shutter. 2 Open orifice. 3 Replace. 4 Tighten. 5 Replace. 6 Adjust.
		3. Both systems. a. Thermostat defective b. Bad contacts.	1. Replace. 2. Correct.
	Mixing valve (double-tank systems only)	1. Valve defective. 2. Sensor defective. 3. Leak in capillary tubing.	1. Replace. 2. Replace. 3. Replace.

Table 3-3. Troubleshooting Guidelines for Draindown Systems (Concluded)

Problem	Components	Possible Causes	Corrective Action
Hot water temperature not high enough	Hot water thermostat	1. Thermostat setting too low. 2. Thermostat out of calibration.	1. Set thermostat higher. 2. Recalibrate or replace thermostat.
	Auxiliary heater	Undersized heater for hot water demand.	Replace when heater fails.
	Safety switch	Set too low.	Check and reset.
System leaks	Pipe joints	1. Thermal expansion and contraction. 2. Joint improperly made.	1. Provide flexibility and reassemble. 2. Reassemble leaky joint.
	Hose connections	Clamp does not hold tight.	Tighten up the hose clamp. Replace clamp or hose.
	Relief valve	1. Improper pressure setting. 2. Defective component.	1. Check pressure setting and correct. 2. Replace.
Poor solar energy collection	Collector array	1. Undersized collector area. 2. Collectors shaded 3. Flow rate too high or too low. 4. Heat transfer surface covered with scale deposits 5. Leaks.	1. Install more collector area. 2. Remove obstacle or install collectors in more appropriate location. 3. Rebalance flow. 4. Flush collector loop. 5. Repair.
	Piping	1. Insufficient insulation. 2. Improper weather protection. 3. Insulation damaged.	1. Add additional insulation. 2. Provide proper weather protection. 3. Repair.
System noisy when operating	Pump cavitation	1. Restricted pump suction line. 2. Air in the system.	1. Remove restrictions. 2. Manually vent the system if automatic air vents are not adequate.
	Pump bearings	1. Bearing worn. 2. Bearing damaged due to improper alignment.	1. Replace. 2. Properly align pump and motor shaft.
	Air vents	Improperly sized.	Install proper air vents.
	Burner (double-tank systems only)	1. Burner clogged. 2. Undersized burner orifice.	1. Clean. 2. Provide correctly-sized orifice.
	Mixing valve (double-tank systems only)	1. Sensor out of calibration. 2. Temperature set too low. 3. Valve spring too weak.	1. Recalibrate. 2. Reset. 3. Replace
Water temperature too high	Hot water temperature	1. Thermostat seeting too high. 2. Thermostat out of calibration. 3. Bad contacts.	1. Reset. 2. Recalibrate. 3. Correct.
	Sensor	Out of calibration.	Recalibrate or replace.
	Mixing valve (double-tank systems only)	1. Sensor out of calibration. 2. Temperature set too high.	1. Recalibrate. 2. Reset.

Source: Argonne National Laboratory. Interim Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems, ANL/SDP-9; Solar/0907-80/70

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Table 3-4. Troubleshooting Guidelines for Drainback Systems

Problem	Components	Possible Causes	Corrective Action
System does not start	Power supply	1. Tripped on overload.	1. Determine cause and replace fuse or breaker.
		2. Open circuit breaker.	2. Check and close.
		3. Defective transformer.	3. Replace.
		4. Line voltage fluctuating.	4. Inform power company.
		5. Brownout.	5. Provide brownout protective device and inform power company.
		6. Control switch on "off position.	6. Turn to "auto" position.
	Thermostat	1. High and low temperature differential set points too high.	1. Reset according to specifications and/or results obtained during system start-up and testing.
		2. Defective component.	2. Replace thermostat.
		3. Loose contacts.	3. Tighten wires.
		4. Thermostat is out of calibration.	4. Recalibrate.
	Sensor	1. Defective.	1. Replace.
		2. Improper installation.	2. Reinstall.
		3. Defective control cable.	3. Replace.
		4. Sensor out of calibration.	4. Recalibrate.
	Pump	1. Motor failure.	1. Check brush holders, throw-out mechanisms, centrifugal switches, or other mechanical components that may be loose, worn, dirty, or gummy. Replace worn components and reassemble.
		2. Overload protection switch shuts down pump motor.	2. Determine cause of overloading; check if balancing valve is in proper position.
		3. Defective shaft, impeller, or coupling.	3. Replace.
		4. Defective bearings.	4. Replace.
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
System starts but cycles	Thermostat	High and low temperature differential set points are too close together.	Reset according to specification and/or results obtained during system start-up and testing.
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
Pump runs but water does not flow to collectors	Isolation pump valve(s)	Valve(s) closed.	Open valve(s).
	Pump impeller	Impeller broken or separated from shaft	Replace impeller and/or shaft assembly.
	Blocked liquid flow passage	Pipe damaged.	Replace damaged section.
System runs continuously	Thermostat	1. Low temperature differential set point set too low.	1. Reset according to specifications or setting determined during start-up.
		2. Defective component.	2. Replace thermostat.
		3. Thermostat is out of calibration.	3. Recalibrate.
	Sensor(s)	1. Defective sensor(s).	1. Replace.
		2. Sensor(s) is out of calibration.	2. Recalibrate.
	Control circuitry	1. Bad contacts.	1. Check and correct.

Table 3-4. Troubleshooting Guidelines for Drainback Systems (Continued)

Problem	Components	Possible Causes	Corrective Action
System leaks	Pipe joints	1. Thermal expansion and contraction. 2. Joint improperly made.	1. Provide flexibility and reassemble. 2. Reassemble leaky joint.
	Hose connection	Clamp does not hold tightly.	Tighten up the hose clamp, replacing clamp or hose if necessary.
	Relief valve	1. Improper pressure setting. 2. Defective component.	1. Check pressure setting and correct. 2. Replace.
Poor solar energy collection	Collector array	1. Undersized collector area. 2. Collectors shaded. 3. Flow rate too high or too low. 4. Heat transfer surface covered with scale deposits. 5. Leaks.	1. Install more collector area. 2. Remove obstacle or install collectors in sunlit location. 3. Rebalance flow. 4. Flush collector loop. 5. Repair.
	Piping	1. Insufficient insulation. 2. Improper weather protection. 3. Insulation damaged.	1. Add additional insulation. 2. Provide proper weather protection. 3. Repair.
	Heat exchanger	1. Undersized. 2. Clogged.	1. Install properly sized unit. 2. Clean heat exchanger.
System noisy when operating	Pump cavitation	1. Restricted pump suction line. 2. Air in the system.	1. Remove restrictions. 2. Manually vent the system if automatic air vents are not adequate.
	Pump bearings	1. Bearing worn. 2. Bearing damaged due to misalignment.	1. Replace. 2. Align pump and motor shaft.
	Piping	1. Air locked in the piping. 2. Piping vibrates.	1. Air vent the system. 2. Provide adequate pipe support.
No hot water	Make-up water shut-off valve	Valve closed.	Open valve.
	Heater failed to actuate	1. Electric heater, single-tank systems. a. No power to electric heater (single-tank systems only).	a. Check overload protection and correct.
		2. Gas heater, two-tank systems only. a. Failure to ignite (gas off). b. Safety switch malfunctioning. c. Defective thermocouple and/or automatic pilot valve. d. Pilot won't stay lit 1 Too much primary air. 2 Dirt in pilot orifice. 3 Pilot valve defective. 4 Loose thermocouple connection. 5 Defective thermocouple. 6 Improper pilot gas adjustment.	a. Open manual valve. b. Check and replace. c. Check and replace. d. 1 Adjust pilot shutter. 2 Open orifice. 3 Replace. 4 Tighten. 5 Replace. 6 Adjust.
		3. Both systems a. Thermostat defective. b. Bad contacts.	a. Replace. b. Correct.
	Temperature modulating valve	1. Valve defective. 2. Sensor defective.	1. Replace. 2. Replace.

Table 3-4. Troubleshooting Guidelines for Drainback Systems (Concluded)

Problem	Components	Possible Causes	Corrective Action
Hot water temperature not high enough	Hot water thermostat	1. Thermostat setting two low. 2. Thermostat out of calibration.	1. Set thermostat higher. 2. Recalibrate or replace thermostat.
	Auxiliary heater	Heater undersized for hot water demand	Replace when heater fails.
	Safety switch	Set too low.	Check and reset.
	Burner (two-tank systems only)	1. Burner clogged. 2. Undersized burner orifice.	1. Clean. 2. Provide correct size orifice.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too low. 3. Valve spring too weak.	1. Recalibrate. 2. Reset. 4. Replace.
Water temperature too high	Hot water temperature thermostat	1. Thermostat setting too high. 2. Thermostat out of calibration. 3. Bad contacts.	1. Reset. 2. Recalibrate. 3. Correct.
	Sensor	Out of calibration	Recalibrate or replace.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too high.	1. Recalibrate. 2. Reset.

Source: Argonne National Laboratory. Interim Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems, ANL/SDP-9; Solar/0907-80/70

Table 3-5. Troubleshooting Guidelines for Closed-Loop Antifreeze Systems

Problem	Components	Possible Causes	Corrective Action
System does not start	Power supply	1. Tripped on overload.	1. Determine cause and replace fuse or breaker.
		2. Open circuit breaker.	2. Check and close.
		3. Defective transformer.	3. Replace.
		4. Line voltage fluctuating.	4. Inform power company.
		5. Brownout.	5. Provide brownout protective device and inform power company.
		6. Control switch on "off position.	6. Turn to "auto" position.
	Thermostat	1. High and low temperature differential set points too high.	1. Reset according to specifications and/or results obtained during system start-up and testing.
		2. Defective component.	2. Replace thermostat.
		3. Loose contacts.	3. Tighten wires.
		4. Thermostat is out of calibration.	4. Recalibrate.
	Sensor	1. Defective.	1. Replace.
		2. Improper installation.	2. Reinstall.
		3. Defective control cable.	3. Replace.
		4. Sensor out of calibration.	4. Recalibrate.
	Pump	1. Motor failure.	1. Check brush holders, throw-out mechanisms, centrifugal switches, or other mechanical components that may be loose, worn, dirty, or gummy. Replace worn components and reassemble.
		2. Overload protection switch shuts down pump motor.	2. Determine cause of overloading; check if balancing valve is in proper position.
		3. Defective shaft, impeller, or coupling.	3. Replace.
		4. Defective bearings.	4. Replace.
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
System starts but cycles	Thermostat	High and low temperature differential set points are too close together.	Reset according to specification and/or results obtained during system start-up and testing.
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
Pump runs but liquid does not flow to collectors	Supply valve closed	1. Valve sticks.	1. Repair valve.
	System air-locked	Air vent(s) jammed closed.	Replace vent(s).
	Pump impeller	Impeller broken or separated from shaft.	Replace impeller and/or shaft assembly.
	Blocked liquid flow passage	Pipe damaged.	Replace damaged section.
System runs continuously	Thermostat	1. Low temperature differential set point set too low.	1. Reset according to specifications or setting determined during start-up.
		2. Defective component.	2. Replace thermostat.
		3. Thermostat is out of calibration.	3. Recalibrate.
	Sensor(s)	1. Defective sensor(s).	1. Replace.
		2. Sensor(s) is out of calibration.	2. Recalibrate.
	Control circuitry	1. Bad contacts.	1. Check and correct.

Table 3-5. Troubleshooting Guidelines for Closed-Loop Antifreeze Systems (Continued)

Problem	Components	Possible Causes	Corrective Action
System leaks	Pipe joints	1. Thermal expansion and contraction. 2. Joint improperly made.	1. Provide flexibility and reassemble. 2. Repair leaky joint.
	Hose connection	Clamp does not hold tightly.	Tighten up the hose clamp. Replace clamp or hose.
	Relief valve	1. Improper pressure setting. 2. Defective component.	1. Check pressure setting and correct. 2. Replace.
		2. Gas heater, two-tank systems only.	
		a. Failure to ignite (gas off).	a. Open manual valve.
		b. Safety switch malfunctioning.	b. Check and replace.
		c. Defective thermocouple and/or automatic pilot valve.	c. Check and replace
		d. Pilot won't stay lit	d.
		1 Too much primary air.	1 Adjust pilot shutter.
		2 Dirt in pilot orifice.	2 Open orifice.
		3 Pilot valve defective.	3 Replace.
		4 Loose thermocouple connection.	4 Tighten.
		5 Defective thermocouple.	5 Replace.
		6 Improper pilot gas adjustment.	6 Adjust.
		3. Both systems	
		a. Thermostat defective.	a. Replace.
		b. Bad contacts.	b. Correct.
	Temperature modulating valve	1. Valve defective. 2. Sensor defective.	1. Replace. 2. Replace.
Hot water temperature not high enough	Hot water thermostat	1. Thermostat setting two low. 2. Thermostat out of calibration.	1. Set thermostat higher. 2. Recalibrate or replace thermostat.
	Auxiliary heater	Heater undersized for hot water demand	Replace when heater fails.
	Safety switch	Set too low.	Check and reset.
	Burner (two-tank systems only)	1. Burner clogged. 2. Undersized burner orifice.	1. Clean. 2. Provide correctly sized orifice.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too low. 3. Valve spring too weak.	1. Recalibrate. 2. Reset. 4. Replace.
Poor solar energy collection	Collector array	1. Undersized collector area. 2. Collectors shaded. 3. Flow rate too high or too low. 4. Heat transfer surface covered with scale deposits. 5. Leaks.	1. Install more collector area. 2. Remove obstacle or install collectors in sunlit location. 3. Rebalance flow. 4. Flush collector loop. 5. Repair.
	Piping	1. Insufficient insulation. 2. Improper weather protection. 3. Insulation damaged.	1. Add additional insulation. 2. Provide proper weather protection. 3. Repair.
	Collector fluid	1. Antifreeze/water concentration in collector loop fluid is improper. 2. Collector loop degraded.	1. Provide proper insulation. 2. Follow manufacturer's recommendations.

Table 3-5. Troubleshooting Guidelines for Closed-Loop Antifreeze Systems (Concluded)

Problem	Components	Possible Causes	Corrective Action
System noisy when operating	Pump cavitation	1. Restricted pump suction line. 2. Air in the system.	1. Remove restrictions. 2. Manually vent the system if automatic air vents are not adequate.
	Pump bearings	1. Bearing worn. 2. Bearing damaged due to improper alignment.	1. Replace 2. Properly align pump and motor shaft.
	Piping	1. Air locked in the piping. 2. Piping vibrates.	1. Air vent the system. 2. Provide adequate pipe support.
	Air vents	Improperly sized.	Install proper air vents.
No hot water	Make-up water shut-off valve	Valve closed.	Open valve.
	Heater failed to actuate	1. Electric heater, single-tank systems. a. No power to electric heater (single-tank systems only).	a. Check overload protection and correct.
Water temperature too high	Hot water temperature thermostat	1. Thermostat setting too high. 2. Thermostat out of calibration. 3. Bad contacts.	1. Reset. 2. Recalibrate. 3. Correct.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too high.	1. Recalibrate. 2. Reset.

Source: Argonne National Laboratory. Interim Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems, ANL/SDP-9; Solar/0907-80/70

Table 3-6. Troubleshooting Guidelines for Two-Tank Air Systems

Problem	Components	Possible Causes	Corrective Action
System does not start	Power supply	1. Tripped on overload.	1. Determine cause and replace fuse or breaker.
		2. Open circuit breaker.	2. Check and close.
		3. Defective transformer.	3. Replace.
		4. Line voltage fluctuating.	4. Inform power company.
		5. Brownout.	5. Provide brownout protective device and inform power company.
		6. Control switch on "off position.	6. Turn to "auto" position.
	Thermostat	1. High and low temperature differential set points too high.	1. Reset according to specifications and/or results obtained during system start-up and testing.
		2. Defective component.	2. Replace thermostat.
		3. Loose contacts.	3. Tighten wires.
		4. Thermostat is out of calibration.	4. Recalibrate.
	Sensor	1. Defective.	1. Replace.
		2. Improper installation.	2. Reinstall.
		3. Defective control cable.	3. Replace.
		4. Sensor out of calibration.	4. Recalibrate.
	Pump and/or fan	1. Motor failure.	1. Check brush holders, throw-out mechanisms, centrifugal switches, or other mechanical components that may be loose, worn, dirty, or gummy. Replace worn components and reassemble.
		2. Overload protection switch shuts down pump motor.	2. Determine cause of overloading; check if balancing valve is in proper position.
		3. Defective shaft, impeller, or coupling.	3. Replace.
		4. Defective bearings.	4. Replace.
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
System starts but cycles	Thermostat(s)	High and low temperature differential set points are too close together.	Reset according to specification and/or results obtained during system start-up and testing.
	Time-delay relay	Time delay "times out" too soon (sensors do not heat up in time).	Increase time-delay relay setting.
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
Pump runs but no water flows to the heat exchanger	Valve closed	1. Actuator defective	1. Replace actuator
		2. No power to actuator.	2. Check wiring.
		3. Valve sticks.	3. Cycle valve by jumping control system or replace actuator.
	System air-locked	1. Poor pump inlet connection.	1. Remake according to good installation practice.
		2. Air vent(s) jammed closed.	2. Replace vent(s).
	Pump impeller	Impeller broken or separated from shaft.	Replace impeller and/or shaft assembly.
	Blocked liquid flow passage	Pipe damaged.	Replace damaged section.
Fan runs but no air to the heat exchanger	Damper(s)	1. Actuator defective.	1. Replace actuator.
		2. No power to actuator.	2. Check wiring.
		3. Damper linkage defective.	3. Repair or replace.

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Table 3-6. Troubleshooting Guidelines for Two-Tank Air Systems (Continued)

Problem	Components	Possible Causes	Corrective Action
System runs continuously	Thermostat(s)	1. Low temperature differential set point set too low. 2. Defective component. 3. Thermostat is out of calibration.	1. Reset according to specifications or settings determined during start-up. 2. Replace thermostat. 3. Recalibrate.
	Sensor(s)	1. Defective sensor(s). 2. Sensor(s) is out of calibration.	1. Replace 2. Recalibrate.
	Control circuitry	Bad contacts.	Check and correct.
System does not provide freeze proection	Valve closed	1. Actuator defective. 2. No power to actuator. 3. Valve sticks.	1. Replace actuator. 2. Check control wiring. 3. Cycle valve by jumping control system, or replace actuator.
	Freeze protection thermostat	1. Set point has drifted. 2. Defective components. 3. Loose contacts. 4. Themostat is out of calibration.	1. Reset. 2. Replace. 3. Tighten wires. 4. Recalibrate.
	Freeze Sensor	1. Sensor out of calibration. 2. Defective sensor. 3. Improper installation.	1. Calibrate. 2. Replace. 3. Reinstall.
	Power supply and pump	See power supply and pump causes.	See power supply and pump causes.
	Control circuitry	Bad contacts.	Check and correct.
	Dampers	1. Damper linkage defective. 2. Shaft broken.	1. Repair or replace. 2. Replace.
Air system leaks	Duct joints at collector	1. Thermal expansion and contraction. 2. Joint improperly made.	1. Provide flexibility and reassemble. 2. Reassemble leaky joint
	Hose connection	Clamp does not hold tightly.	Tighten hose clamp. Replace clamp or hose.
	Collectors on systems where collector panels butt together	1. Seals leak. 2. Clamps or other methods of joining.	1. Replace. 2. Tighten up joints between panels.
	Heater failed to actuate	1. Failure to ignite a. Gas off. b. Safety switch malfunctioning. c. Defective thermocouple and/or automatic pilot valve.	1. a. Open manual valve. b. Check and replace. c. Check and replace
		2. Pilot won't stay lit. a Too much primary air. b. Dirt in pilot orifice. c. Pilot valve defective. d. Loose thermocouple connection. e. Defective thermocouple. f. Improper pilot gas adjustment.	2. a. Adjust pilot shutter. b. Open orifice. c. Replace. d. Tighten. e. Replace. f. Adjust.
		3. Thermostat defective 4. Bad contacts.	3. Replace 4. Correct.
	Temperature modulating valve	1. Valve defective. 2. Sensor defective. 3. Leak in capillary tubing.	1. Replace. 2. Replace. 3. Replace.

Table 3-6. Troubleshooting Guidelines for Two-Tank Air Systems (Concluded)

Problem	Components	Possible Causes	Corrective Action
Hot water temperature not high enough	Hot water thermostat	1. Thermostat setting two low. 2. Thermostat out of calibration.	1. Set thermostat higher. 2. Recalibrate or replace thermostat.
	Auxiliary heater	Heater undersized for hot water demand	Replace when heater fails.
	Safety switch	Set too low.	Check and reset.
	Burner	1. Burner clogged. 2. Undersized burner orifice.	1. Clean. 2. Provide correctly sized orifice.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too low. 3. Valve spring too weak.	1. Recalibrate. 2. Reset. 3. Replace
Poor solar energy collection	Collector array	1. Undersized collector area. 2. Collectors shaded. 3. Air flow rate too high or too low. 4. Leaks.	1. Install more collector area. 2. Remove obstacle or install collectors in sunlit location. 3. Check collector loop and rebalance flow. 4. Repair.
	Ductwork	1. Insufficient insulation. 2. Improper weather protection. 3. Insulation damaged.	1. Add additional insulation. 2. Provide proper weather protection. 3. Repair.
	Heat exchanger	1. Undersized heat echanger. 2. Heat transfer surface covered with dirt and scale deposits.	1. Install adequate heat exchanger. 2. Clean surface.
System noisy when operating	Fan	Fan noise too high.	Attenuate noise if annoying.
	Pump	1. Restricted pump suction results in cavitation. 2. Air in the system.	1. Remove restrictions. 2. Manually vent the system if automatic air vents are not adequate.
	Pump or fan bearings	1. Bearing worn. 2. Bearing damaged due to misalignment.	1. Replace. 2. Align pump and motor shaft.
	Piping	1. Air locked in the piping. 2. Piping vibrates.	1. Vent system. 2. Provide adequate pipe support.
	Air vents	Improperly sized.	Install proper air vents.
No hot water	Make-up water shut-off valve	Valve closed.	Open valve.
Water temperature too high	Hot water thermostat	1. Thermostat setting too high. 2. Thermostat out of calibration. 3. Bad contacts.	1. Reset. 2. Recalibrate. 3. Correct.
	Sensor	Out of calibration.	Recalibrate or replace.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too high.	1. Recalibrate. 2. Reset.

Source: Argonne National Laboratory. Interim Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems,

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CHAPTER 4

HOUSING CONSTRUCTION

Installers of renewable resource program measures must be knowledgeable about residential construction methods and structural characteristics in order to correctly install a solar device. Inspectors will have to verify that a safe and correct installation has been made. This chapter addresses the construction details necessary for the installer and inspector to know.

4.1 INTRODUCTION

In examining the different methods of residential construction in existence today, it becomes apparent that nearly all houses share some basic similarities. Whether a house is constructed of wood, concrete block, brick, adobe, or logs; or whether it is built in the temperate south or the cold north country, it must have:

- foundation,
- floors,
- walls, and
- roof.

This section will provide a brief overview with emphasis placed on function, possible materials, and special considerations with regards to solar retrofit for each of the four building components mentioned above.

4.2 FOUNDATIONS

4.2.1 Function

The most logical way to approach a discussion of a foundation is to examine its prime functions:

- To transfer and distribute building loads to the ground;
- To prevent building uplift, overturning, and horizontal sliding;
- To keep the building high and dry; and
- To prevent motion due to frost.

To Transfer and Distribute Building Loads to the Ground

The foundation must support the total weight of the building and distribute that weight evenly to the ground. The total weight of a building can be thought of as the sum of its

- Dead loads or actual weight of the house itself ;
- Live loads,or the weight of its occupants, furnishings, appliances, etc.;
- Snow loads,or the weight of snow accumulation on the roof ; and
- Seismic loads.

The dead loads of a building are the sum of the weights of its floors, walls, and roof. Typical wall and floor dead loads for frame construction run about 5 psf of surface area while typical dead loading for roofs runs about 7-1/2 psf of surface area.

Live loads are dictated by the National Building Code as follows:

First Floor (living rooms, kitchens, etc.)	40 psf
Second Floor (bedrooms, bath)	30 psf
Attic (unoccupied)	20 psf

Snow loads vary regionally and can attain values as high as 40 psf.

Seismic activity can place on a structure additional loads that must be accounted for.

To Prevent Building Uplift, Overturning and Horizontal Sliding

To prevent a building from being either lifted off or sliding on its foundation, it must be effectively anchored to counteract the forces of wind. The roof of a house is similar to an airfoil. The increased velocity of airflow over the roof surface results in a lower pressure above the roof and higher pressure below. This is lift. In addition, if the house has a large eave or overhang, the lifting force is even greater, because the wind can push from below as well as pull from above. This lifting force combined with the horizontal, or pushing force of wind can cause an improperly anchored building to slide on its foundation. In the most extreme case, a combination of these forces can even cause a building to be lifted and overturned.

To Keep the Building High and Dry

An important function of a foundation is to isolate a building from prolonged contact with ground moisture. Untreated wood in contact with moisture will soon begin to deteriorate. Although concrete (a common foundation material) does have a tendency to attract water from the surrounding ground, the structure can be adequately protected from the ill-effects of moisture by employing at least one and preferably a combination of the following methods:

- Treat sills with a moisture resistant preservative.
- Use a water resistant barrier such as polyethylene sheeting between sills and foundation.
- Keep the sills a minimum of 12 in. above the ground.
- Provide for adequate drainage outside the foundation wall.

To Prevent Motion Due to Frost

Water expands significantly upon freezing, about 4% by volume, resulting in a surface displacement in heavily moisture-saturated soils of up to one-half inch for every foot of frost penetration. In the cold northern locations where frost penetration can reach to depths of 72 in., surface displacement or frost heaving can be quite pronounced. While adequate drainage of the soil will alleviate the problem to a great degree, a foundation that extends below the level of frost penetration will ensure against damage due to uneven frost heaving and subsequent settling.

Having established the necessary functions of a foundation, the accepted methods by which these functions are performed can now be examined.

4.2.2 Types

Poured-in-Place, Continuous Concrete Wall

Poured in place concrete walls (Fig. 4-1) are the most common type of foundation. This system typically consists of an 8-in. thick concrete wall poured over an 8 x 16 in. poured concrete footing. Both walls and footings support the entire perimeter of the building and usually contain horizontal and/or vertical sections of steel reinforcing bar. In instances where foundations are poured on firm bedrock, use of footings can be eliminated.

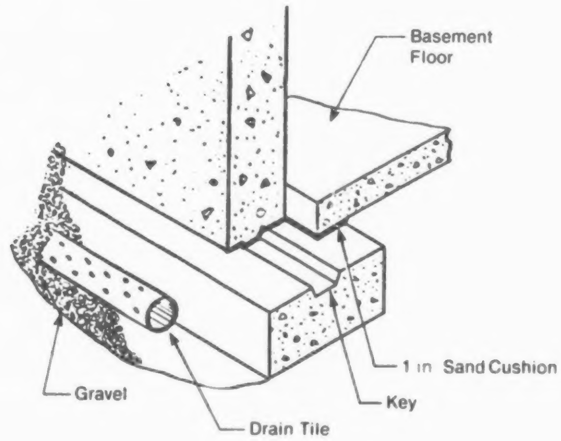


Figure 4-1. Poured-in-Place Concrete Wall With Basement

The common basement is formed using this foundation technique. The entire building site is excavated to the desired depth, (usually 6 to 7 ft) the footings and walls are poured, and then a concrete floor slab is poured, just above the footings. If the same procedure is followed, but excavation is performed to a lesser depth and the poured concrete floor slab is omitted, the concrete perimeter wall system with crawlspace is described. The same basic system may substitute concrete block for the poured concrete wall (Fig. 4-2). Footings, however, are almost always of poured concrete. It should be noted that while the existence of a basement or crawlspace has little to do with the functions of a foundation, they frequently contain thermal storage tanks and other components used in active solar systems.

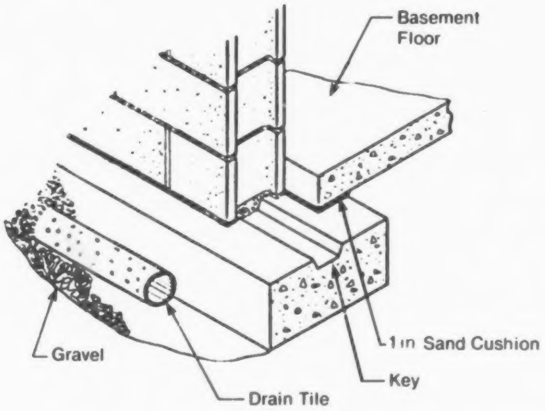


Figure 4-2. Concrete Block Wall With Basement

Slab on Grade Foundation

Concrete slab on grade foundations (Fig. 4-3) are very popular for two reasons: they provide both foundation and first floor at relatively low cost. A concrete slab on grade usually consists of a 4- or 8-in. thick concrete floor poured over 4 in. of sand or gravel and wire mesh. The edges of the slab should extend downward to a depth equal to the maximum level of frost penetration. This arrangement is often referred to as a thickened edge slab.

If storage space below grade is not desired, the slab on grade foundation works very well. Because the entire slab acts as a footing, it imposes the lowest soil loading characteristics of all foundation types, while its enormous weight does an excellent job in counteracting the uplifting force of wind. In addition, the slab on grade foundation integrates very well with several passive solar measures. When finished with a layer of brick pavers, stone, or slate, it forms an attractive and durable floor of high thermal mass, capable of the storage and the nighttime release of heat acquired during the day. In addition, the low soil-loading characteristics of the slab on grade foundation work very well in supporting the added mass of a water wall.

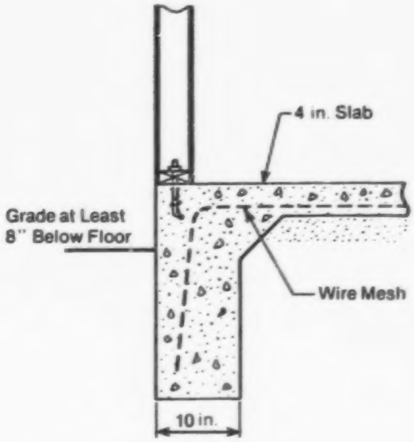


Figure 4-3. Slab on Grade Foundation

Pier and Post Foundations

Many situations in residential construction lend themselves to the use of piers, columns, or posts (Fig. 4-4). It is often cheaper, and just as satisfactory to use piers rather than foundation walls under parts of a building. Posts and columns are usually made of steel or wood, and are used to support beams and girders. The load of these beams and girders is transmitted by the posts and columns to poured concrete footings, which serve to distribute the load over a greater area. Concrete piers fulfill exactly the same function but are usually located underneath the house. Often in mountainous, rocky terrain, entire houses are built on a network of concrete piers.

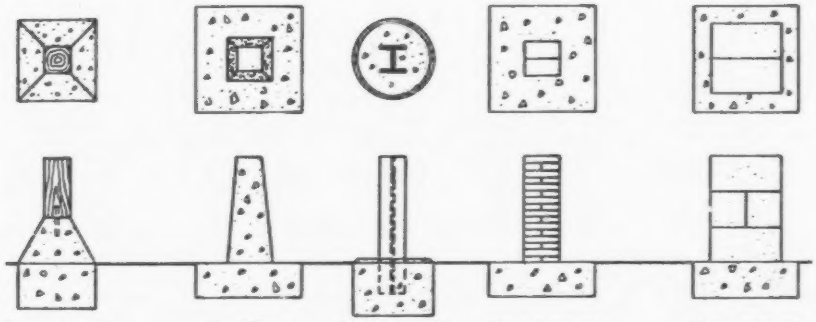

Concrete and Wood Pier
Two Piece Concrete Pier
Concrete and I-Beam Pier
Concrete and Brick Pier
Concrete and Block Pier

Figure 4-4. Types of Piers

Regardless of which type of foundation is used, the building must be securely anchored. This is accomplished through the use of anchor bolts. Usually 10 to 15 in. by at least 1/2 in. in diameter, they are embedded in the wet concrete of the foundation wall or pier. By leaving the threaded end of the bolt protruding a few inches above the surface of the concrete, the walls can be positively secured to the foundation.

4.3 Floor Construction

Floor construction is very similar in nearly all types of residential building. Except in the case of the concrete slab on grade, floors are framed with dimensional lumber, or floor joists (Fig. 4-5). Floor joists usually range from 2 x 6 in. to 2 x 12 in., and are usually spaced 16 in. apart. The distance which joists must span is usually so great that a beam or bearing wall is needed to reduce the span. The beam may be solid timber, laminated or built up from dimensional lumber, or a steel I-beam. The method by which the ends of the floor joists are supported will be covered in detail in Sec. 4.4 (wall systems). For now, suffice it to say that first story floor joists bear on the foundation, and second story joists (Fig. 4-6) are supported by the walls of the house (Fig. 4-6). Once the joists are securely held in place, the subfloor can be applied. Older homes predominantly made use of 1 x 4 in. and 1 x 6 in. boards for subfloors. Recent years have seen this practice replaced with the use of 4 x 8 ft sheets of plywood or particle board, due to the comparatively shorter time required to nail the large sheets in place. The floor is now structurally sound, and will remain as is until the finish stage of construction, at which time carpet, tile, or hardwood flooring is applied over the subfloor.

4.4 WALL SYSTEMS

Wall construction methods and materials vary more than perhaps any other aspect of residential building. Although most foundations are of concrete or block, and most floors are either slab on grade or framed with dimensional lumber, the home builder has many options to choose from for the construction of the walls. The most common methods are wood frame and masonry.

4.4.1 Wood Frame Construction

Although there are many variations in wood framing, the two to be considered here are platform (western) framing, and balloon framing.

Platform (Western) Framing

Platform framing (Fig. 4-7) is by far the most widely used method of house framing. The first story of the house is built on a platform consisting of floor joists, box sill, and subfloor, all of which is bolted directly to the foundation through the sill plate. After completion of the first story walls, a second platform is built, identical to the first, as if the first story walls were the foundation. This method of framing incorporates great standardization of skill and material, thus allowing rapid, economical construction. Framing members are conveniently laid out, cut, and nailed together on the subfloor. When the wall framing is complete (Fig. 4-8), it is raised into place, braced, and work proceeds on another wall. Until recently, wall framing in residential construction made exclusive use of 2 x 4 in. framing members with studs placed every 16 in. on center. While this is still quite common, ever-increasing fuel costs have prompted some builders to frame walls with 2 x 6s, placed every 24 in. With roughly the same amount of lumber in a wall of given size, the thicker wall allows two additional inches of insulation.

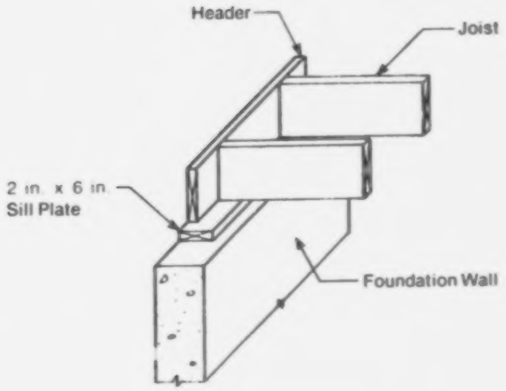

Header
Joist
2 in. x 6 in.
Sill Plate
Foundation Wall

Figure 4-5. Conventional Floor Framing

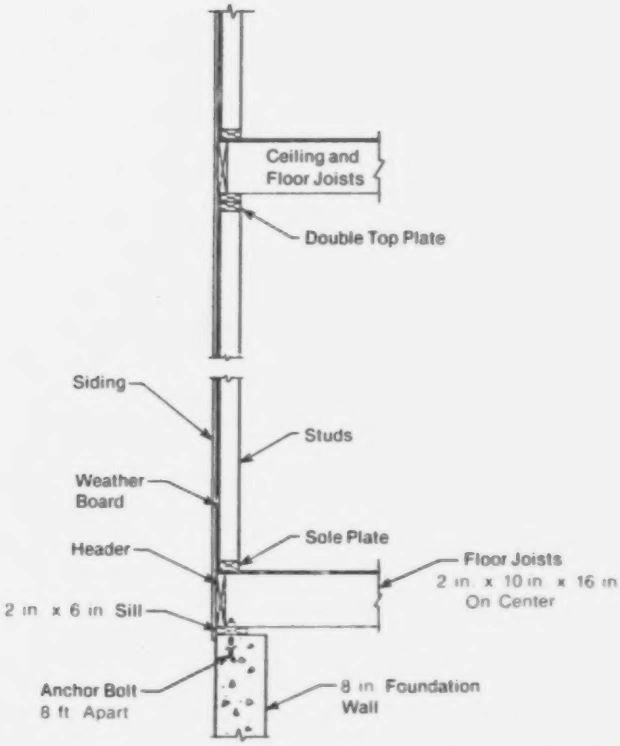

Ceiling and
Floor Joists
Double Top Plate
Siding
Studs
Weather
Board
Sole Plate
Header
Floor Joists
2 in. x 10 in. x 16 in
On Center
2 in x 6 in Sill
Anchor Bolt
8 ft Apart
8 in Foundation
Wall

Figure 4-6. Typical Wall Section – Shows How First and Second Floors are Supported

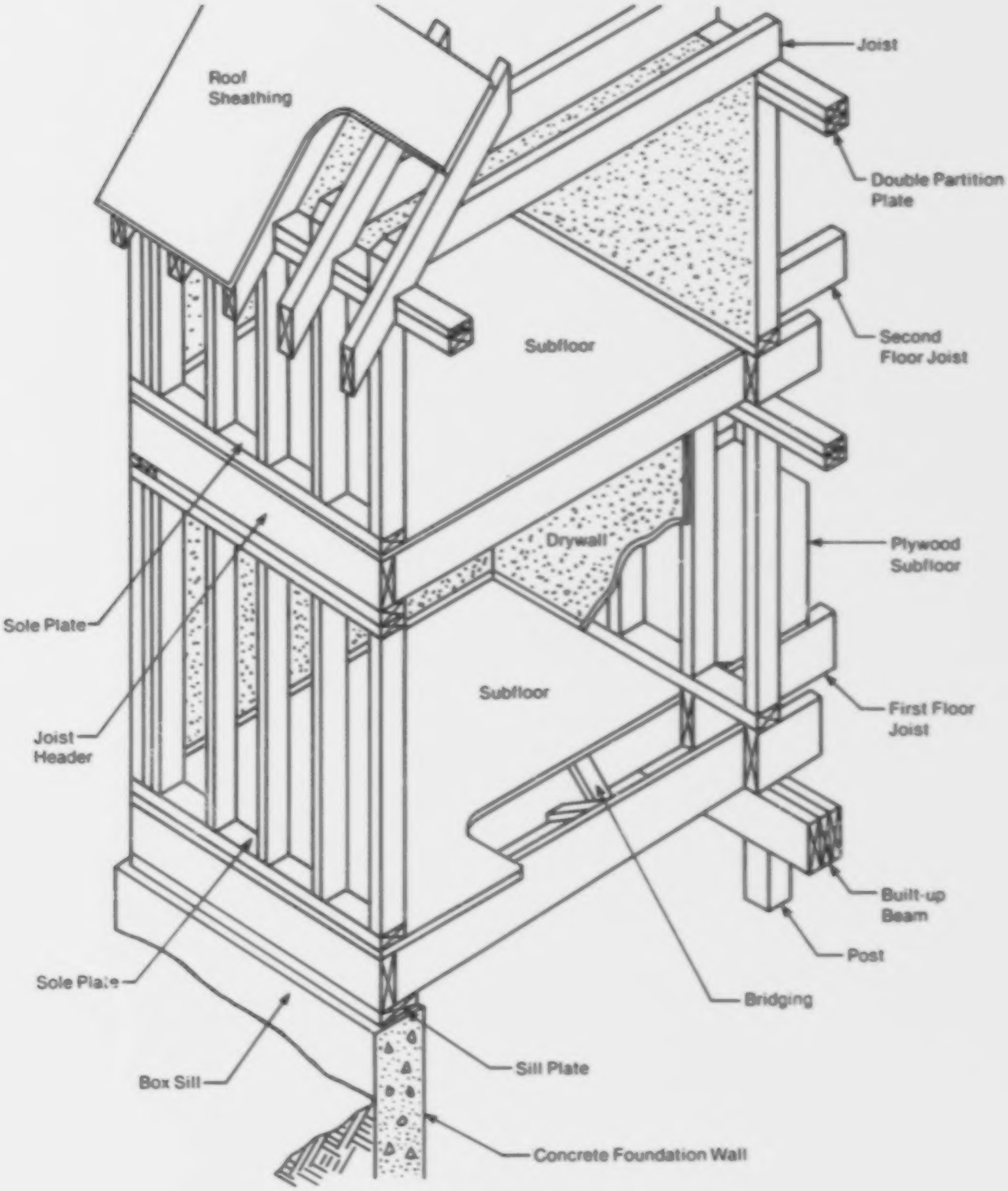

Roof Sheathing
Joist
Double Partition Plate
Second Floor Joist
Subfloor
Drywall
Plywood Subfloor
Sole Plate
Joist Header
Subfloor
First Floor Joist
Built-up Beam
Post
Sole Plate
Bridging
Box Sill
Sill Plate
Concrete Foundation Wall

Figure 4-7. Typical Platform Framing

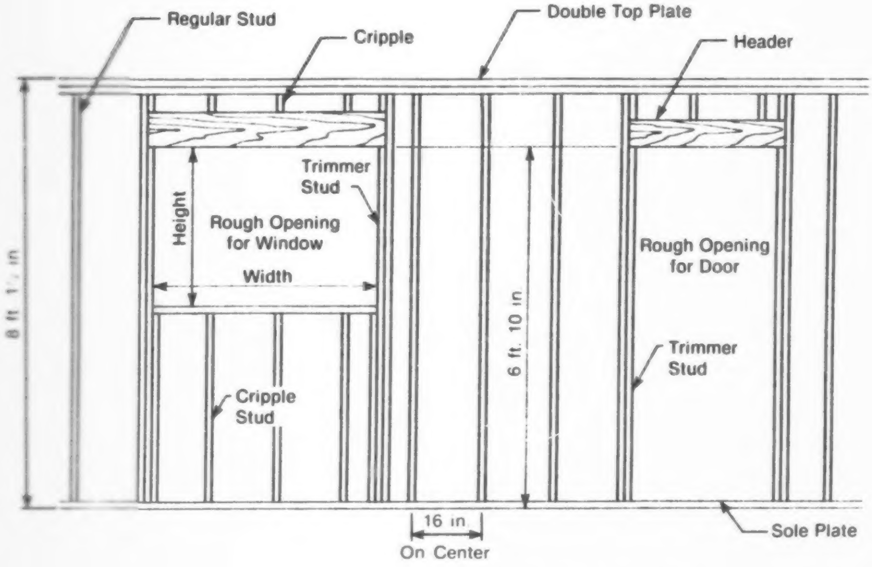

Regular Stud
Cripple
Double Top Plate
Header
Trimmer Stud
Height
Rough Opening for Window
Width
8 ft 1½ in
6 ft. 10 in
Rough Opening for Door
Trimmer Stud
Cripple Stud
16 in.
On Center
Sole Plate

Figure 4-8. Typical Platform Framing

Balloon Framing

Balloon framing (Figs. 4-9, 4-10) was once used extensively, but in recent years has diminished in importance. Its distinguishing feature is that, unlike platform framing where wall studs rest on the subfloor, wall studs in balloon framing rest directly on the sill plate.

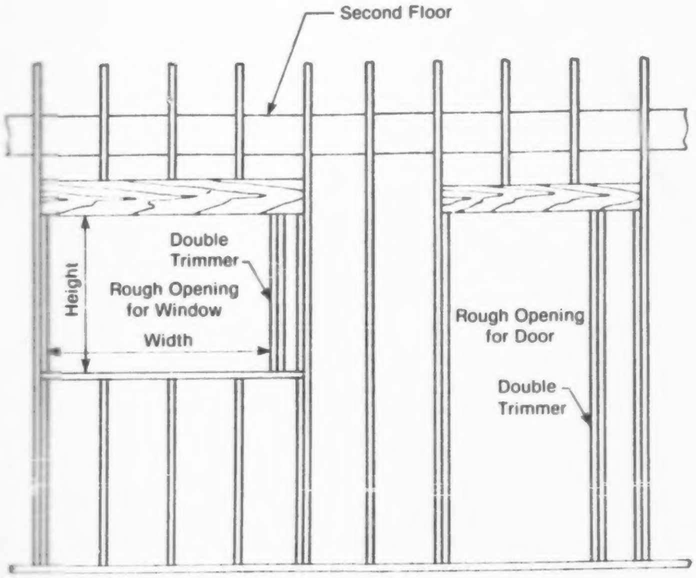

Second Floor
Double Trimmer
Height
Rough Opening for Window
Width
Rough Opening for Door
Double Trimmer

Figure 4-9. Typical Balloon Framing

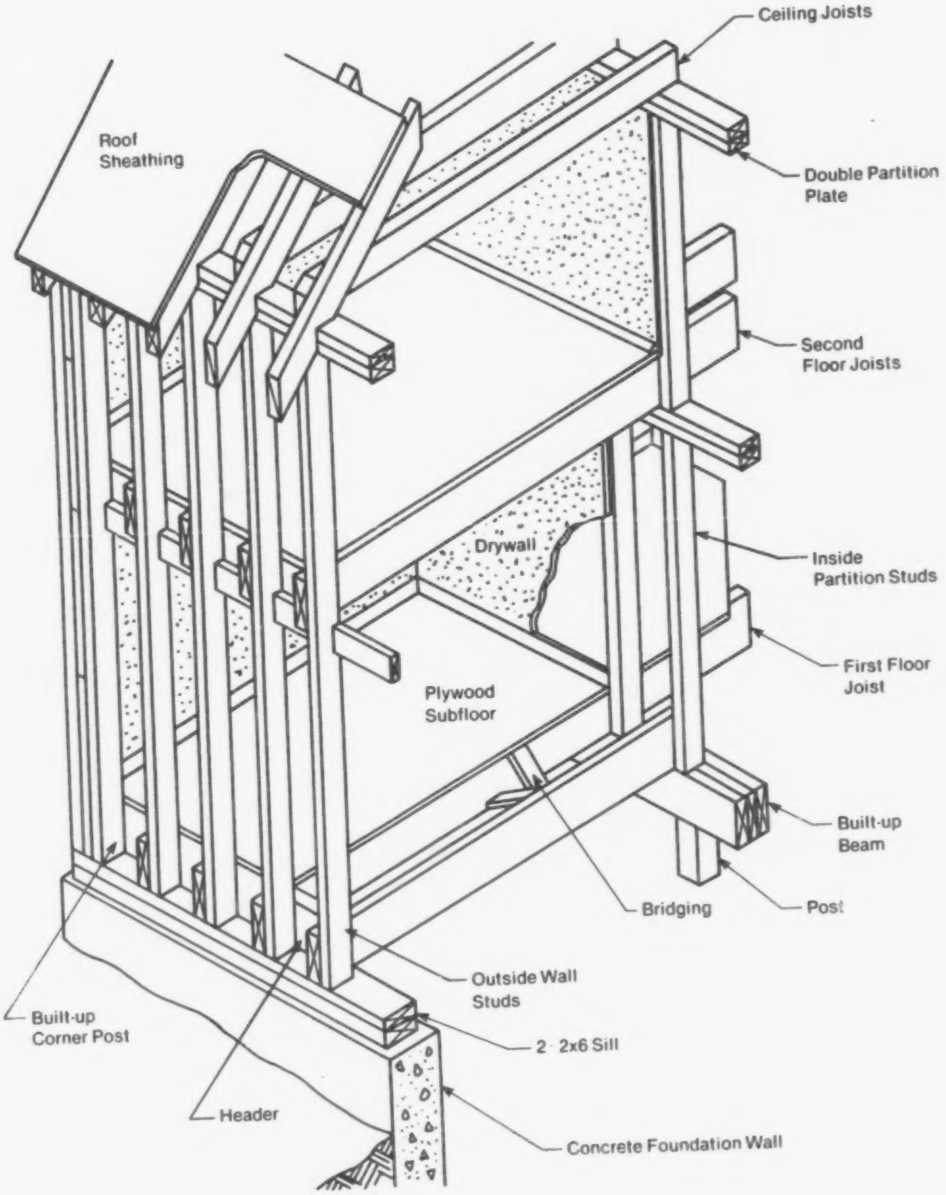

Ceiling Joists
Roof Sheathing
Double Partition Plate
Second Floor Joists
Drywall
Inside Partition Studs
First Floor Joist
Plywood Subfloor
Built-up Beam
Bridging
Post
Outside Wall Studs
Built-up Corner Post
2 - 2x6 Sill
Header
Concrete Foundation Wall

Figure 4-10. Typical Balloon Framing

In a two-or three-story house, the studs run continuously from sill to roof, making the framework like a membrane, thus the term "balloon" framing. Upper story floor joists are supported by a ribband, a 1 x 6 in. or 1 x 8 in. board set into the wall studs. Because lumber shrinks very little in length as it dries (about 1%), balloon framing may still be used in two- and three-story construction with brick veneer or stucco exterior wall finishes. Although shrinkage control is an attractive feature of balloon framing, there are major disadvantages which led to its overall demise:

- Spaces between studs acted like chimney flues in the event of a fire, thus requiring the use of fire-blocking, a time-consuming practice sometimes omitted by framers.
- The ground provided a less than desirable surface to construct a two- or three-story wall, and raising such a wall into place proved difficult.
- Balloon framing dictates the use of much longer framing members, both increasingly harder to find in straight, untwisted lengths, and much more expensive per board foot than the common 8-ft stud.

It should be noted here that passive solar measures such as additional direct gain glazing and thermosyphon air panels (TAP) can be retrofitted to either platform or balloon framing with relative ease. After interior and exterior sheathing is removed, a rough opening for the additional glazing or TAP is constructed in the wall using conventional framing techniques (see Figs. 4-8, 4-9). Sheathing is then re-applied, the glazing or TAP is installed in the rough opening, and trimwork is applied both inside and out to finish the job.

4.4.2 Masonry Wall Construction

A masonry wall is constructed entirely of brick, concrete block, stone, clay tile, terra cotta,or a combination of these materials. In residential construction, concrete block walls are usually of single thickness, whereas brick walls usually require two thicknesses of brick for good lateral stability. Walls of more than one thickness often have an air space between the courses and are bonded together with either a header course of masonry units (Fig. 4-11) or metal wall ties (Fig. 4-12). Floor joists are placed directly into openings in the masonry wall. Each joist is cut at an angle on the end, or firecut (Fig. 4-13) to prevent toppling the wall in the event of a fire collapsing the floor. A top plate is attached to brick walls with anchor bolts embedded between inner and outer courses (Fig. 4-14). A lintel block is used in concrete construction. Anchor bolts are cast in place (Fig. 4-15), and the top plate is bolted to the top of the block wall. Insulation is typically applied by furring out the inside walls with 2 x 2 in. or 2 x 4 in. lumber.

Fiberglass rolls or foam insulation can be placed between the furring strips, and finish wall material (drywall, wood paneling, planking, etc.) applied over the insulation. Insulation may also be applied as foam sheathing on the exterior in conjunction with or prior to installation of the finished surface. Although solid masonry walls were used extensively in the past, due to high cost and difficulty of insulating, solid masonry walls in residential construction have diminished greatly in recent years. The same exterior effect can be obtained with a brick or stone veneer on frame construction (Fig. 4-16). This wall will be better insulated and less expensive to construct. However, with the recent renewed interest in passive solar energy, the solid masonry wall with its high thermal mass is appearing with greater frequency in contemporary construction. It should be noted, however, that many masonry walls which appear solid actually have a two- or three-inch airspace between the inner and outer masonry courses. While the space can significantly add to the insulating value of the wall, this can be a disadvantage in certain instances. An exterior masonry wall with an inside airspace will not perform as well as a glazed trombe wall. The inside airspace will interrupt the flow of solar-derived heat from the exterior to the living area inside. The large airspaces in concrete block walls (unless filled with poured concrete) function in much the same way.

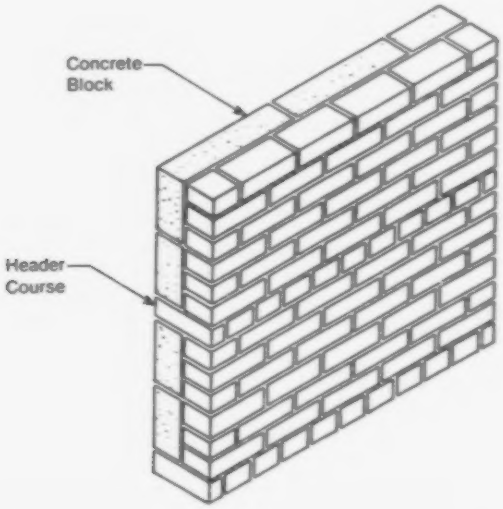


Figure 4-11. Masonry Headers Used To Tie Inner & Outer Walls Together

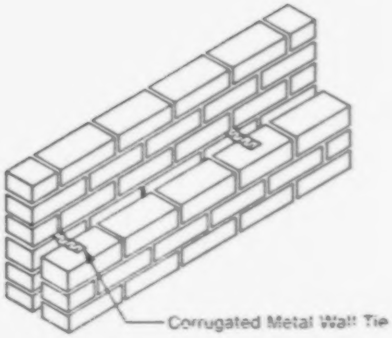


Figure 4-12. Metal Headers Used to Tie Inner and Outer Walls Together

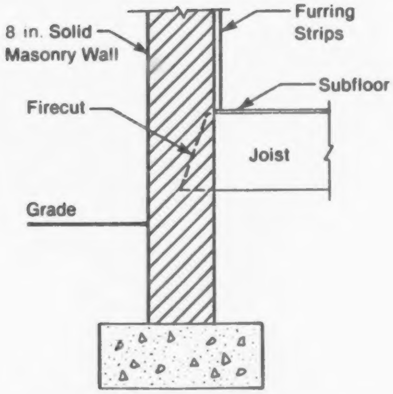

8 in. Solid Masonry Wall
Furring Strips
Subfloor
Firecut
Joist
Grade

Figure 4-13. Wood Floor Joists Supported by Masonry Wall

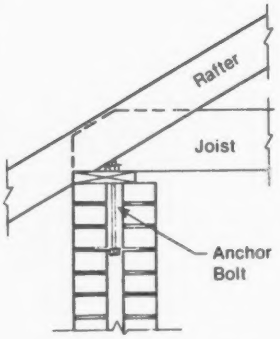

Rafter
Joist
Anchor Bolt

Figure 4-14. Brick Wall

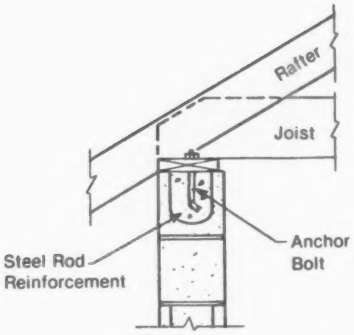

Rafter
Joist
Anchor Bolt
Steel Rod Reinforcement

Figure 4-15. Concrete Block Wall

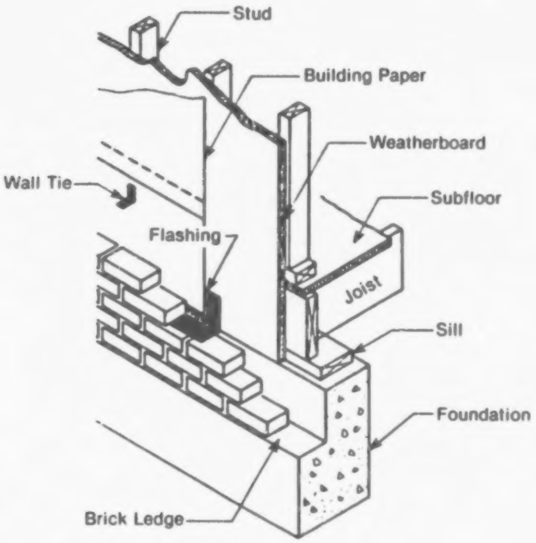


Figure 4-16. Construction Detail of a Brick Veneer Wall Section

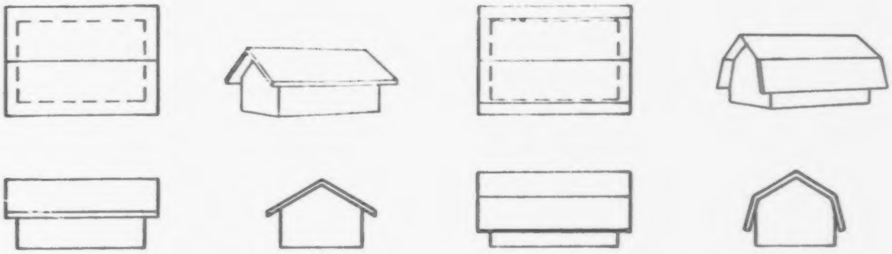
4.5 ROOF CONSTRUCTION

Roof construction is divided into two main groupings. The first considered is the actual structural support systems used in constructing the roof. Among those considered here are conventional framing, prefabricated trusses, and structural decking over an exposed beam. A discussion of various roofing materials follows this discussion.

4.5.1 Structural Support—Conventional Framing

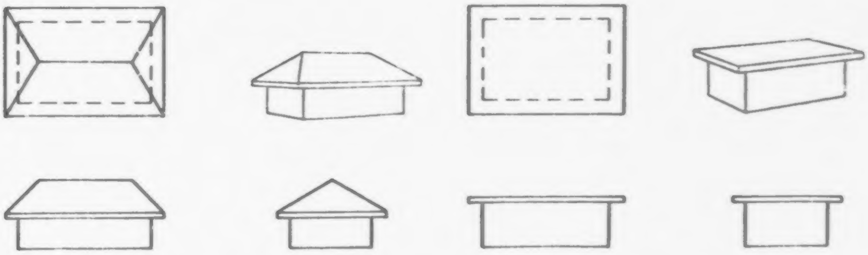
Roof framing consists of several distinct structural elements. The first and most basic of these is the rafter. Common rafters run perpendicular to the wall plate. They extend from the plate (or beyond when an overhang is desired) to the ridge or peak of the roof. Usually spaced 16 in. apart, rafters are of 2 x 6 in., 2 x 8 in., or 2 x 10 in.,depending on the distance that must be spanned. To prevent uplift in high winds, metal fasteners often called hurricane ties are used to secure the rafters to the top plate of the wall. Insulation in rolls or batts is placed between ceiling joists when present, or directly between the rafters in open cathedral ceilings.

Although many different roof designs are possible, the more popular gable, hip, gambrel, shed, and flat roofs (Fig. 4-17) are often constructed using conventional framing techniques.



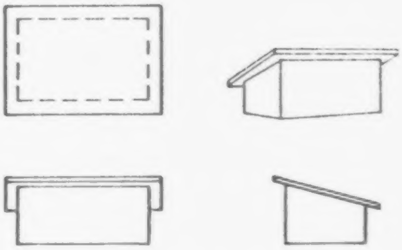
a) Gable Roof

b) Gambrel Roof



c) Hip Roof

d) Flat Roof



e) Shed Roof

Figure 4-17. Types of Roofs

BEST DOCUMENT AVAILABLE

4.5.2 Prefabricated Roof Trusses

Since its relatively recent appearance in residential construction, the prefabricated roof truss has enjoyed tremendous popularity. The prefab roof truss is an assembly of lightweight framing members, usually 2x4s, (Fig. 4-18) fastened together to form a rigid framework. The trusses are placed directly on the wall top plates. Spacing for prefab trusses is usually every 16 or 24 in., although this can vary. The trusses are fastened to the top plates of the wall using metal fastening devices or hurricane ties. As is the case with framed rafters, 1/2-in. plywood sheathing is nailed directly to the tops of the trusses to form the roof deck upon which roofing materials (e.g., shingles) are laid. Ceiling material (usually drywall) is nailed directly to the bottoms of the trusses. Among the reasons for the tremendous popularity of the prefabricated roof truss is savings. Often cheaper than conventional framing, prefab roof trusses are available in a wide variety of shapes, pitches, and sizes (Fig. 4-19). Due to the short time required to erect the trusses, labor costs are minimized as well. Another plus as far as the architect is concerned is the ability to span large distances with lightweight 2 x 4 in. framing.

4.5.3 Structural Decking over Exposed Beams

This method of roof support is often used when the look of heavy exposed beams and natural wood ceilings are desired. Large beams are supported either by heavy posts (thus the name post and beam construction) or by beam pockets framed into wood frame walls and formed into masonry walls. Once these roof beams are in place, structural decking consisting of 2 x 6 in. or 2 x 8 in. boards, often with interlocking tongue and groove,are nailed directly to the beams forming ceiling and roof surface all in one. Both aesthetically pleasing and structurally solid, the only disadvantage to this type of construction, and a significant one, is the difficulty involved in adequately insulating such a roof. Because there are no cavities that can be filled with insulation as is the case with conventional framing or with roof trusses, rigid insulation (usually in 4 x 8 ft sheets, 2 in. thick)is nailed to the top side of the roof decking, and plywood sheathing is nailed on top of that. At this point, the roof is ready to accept the final roofing materials.

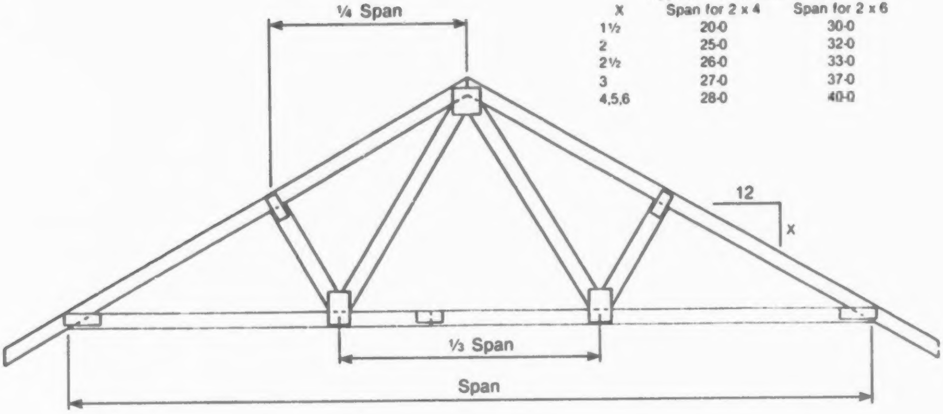
4.5.4 Roofing Materials

Roofing materials vary greatly according to architectural style of the building, local weather conditions, roof pitch, and cost. Whatever roofing material is used should provide a long lasting, durable, waterproof covering. Popular roofing materials include shingles of asphalt, asbestos and wood, asphalt roll roofing, and layers of felt, tar, and gravel sometimes referred to as a built-up roof. Red clay spanish tiles are very popular in the warmer regions of the country. All these roofing materials are usually applied over one or two layers of asphalt-impregnated felt building paper. When asphalt shingle, roll, and built-up roofs are replaced due to wear, the new surface is usually applied directly over the old, worn roof surface.

4.6 RETROFITTING SOLAR SYSTEMS TO EXISTING HOUSES

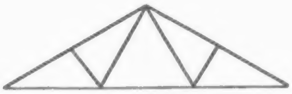
4.6.1 Structural Integrity

In this workbook's section on Active Solar Systems and the HUD Installation Guidelines, consideration is given to the extra loads (weight, wind, snow, seismic) that can be added

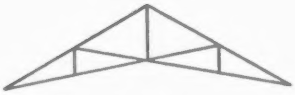


	Approximate Maximum Span	
X	Span for 2 x 4	Span for 2 x 6
1½	20-0	30-0
2	25-0	32-0
2½	26-0	33-0
3	27-0	37-0
4,5,6	28-0	40-0

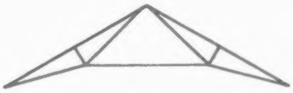
Figure 4-18. Conventional Pitched Roof Truss



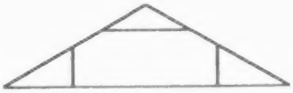
Pitched Truss



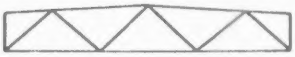
Scissor Truss



Raised Chord Truss



1½ Story Truss



Flat Truss

Figure 4-19. Various Types of Trusses

to the roof of a building when retrofitting with solar collectors. Some states, such as Massachusetts, have a specific section of the building code devoted to this issue, outlining allowable loads under various conditions. In other states, however, it may be necessary to have roof-mount designs analyzed by a registered structural engineer prior to the start of work to ensure that the building's design loads will not be exceeded. This is especially true for structures involving space heating systems utilizing many glazed collector panels and/or smaller systems where racking of collectors can contribute to increased wind and snow loading.

Structural integrity may also be of concern when an existing wall system is to be modified to allow increased south-facing glazing direct-gain heating. In many cases studs are often removed. The weight they had carried must be transferred to the sides of the new opening. This is often done in the same manner as it was done for window openings when the house was under construction, i.e., with horizontal wood or steel members (headers) located immediately above the opening. These rest on strengthened vertical members on each side which carry the weight down to the subfloor or sill plate.

Smaller penetrations of a framed envelope, such as the vents for a TAP, can often be made between framing members, so that structural considerations are not important. However, even relatively small penetrations of a masonry wall should be treated carefully, since the wall itself is load bearing. Steel angle iron is often used to carry the weight across the new opening, acting in the same manner as the headers described above.

The hanging weight of a glazing unit introduces another element of caution into the installation process. It is essential that the fasteners that will hold the vertical TAP onto the outside of the framed envelope be securely placed. A series of wood screws that miss their target could result in torn siding and other costly problems. A similar situation can exist with an improper installation of a glazed frame over a masonry wall.

The structural implications from adding a prefabricated sunspace are most often considered by the manufacturer or in the case of site-built units, by the designer. The questions concerning foundations, wall strength and roof configuration are calculated in advance with attachment to the existing structure a site-specific consideration.

4.6.2 Envelope Tightness

The benefits to be gained by solar retrofit can be lost if careless installation takes place. Since a penetration of the existing thermal envelope is necessary to introduce the heated fluid into the building for immediate use or storage, the complete sealing of that penetration is of utmost importance. Otherwise, infiltration can occur resulting in inflated energy costs.

A safe and enduring installation will include durable gaskets and sealants between the solar component and the existing surface. Construction details should be designed to minimize the distance to be bridged by a sealant, and construction errors remedied with appropriate high quality materials properly placed to ensure a life span equal to that of the balance of the installation. Also, support of the system components should be adequate to withstand environmental conditions that could loosen sealants over time. Some specific examples are:

- Direct gain - the area between rough opening and glazed frame should be completely filled with an expanding foam product before final trim is installed.

- Trombe wall - the space between glazed frame and existing wall should be filled with appropriate sealant. Silicone caulk, unless modified for use on masonry, is not recommended for this. A polyurethane caulk may be necessary to provide long, effective life.
- TAP - the wall penetration should be carefully cut so that the boot is tight-fitting; the boot should be sealed to both inside and outside surfaces to avoid infiltration into and out of the wall cavity. Reverse siphoning should be eliminated by appropriate vent dampers.
- Sunspace - existing doors and windows that will be covered by the sunspace should be well weatherstripped to assist in isolation of the space when desired.
- Active - support of piping should take into account system expansion, contraction, and vibration. Flexible roof gaskets, caulking, and quality roof surface repair around penetration are essential.

4.6.3 Placement of Collectors

Roof Mounts

Generally speaking, solar space heating and pool heating systems require so much of the available south-facing roof surface that there are few options for collector placement—they go where space allows. With solar hot water systems, however, careful placement of collectors is often possible because of the relatively small collection area required. The following comments apply to the placement of collectors for solar hot water systems:

- Collectors should, where possible, be positioned so that the array can be expanded easily in the future. The need for expansion may arise with an increased water heating demand or a decision to use solar heat for an additional application.
- Collectors should be placed where they are easy to service. Solar energy systems do need occasional service; arrays that are not accessible add greatly to cost of repair or replacement.
- Collectors and collector piping should be positioned so as to be completely drainable.
- Collectors should, as much as possible, be kept away from chimneys so that chimney emissions will not collect on glazing and reduce solar collection.
- Collectors should be placed where wind uplift forces will be minimized, particularly when racked away from the roof slope.
- Where possible, collectors should not be placed over entrances in order to avoid injuries from snow slides.
- Collectors should always be placed in the most aesthetically pleasing position possible on the roof, while maintaining the best possible exposure to the sun.

Wall-Mounts

Wherever possible, wall-mounts should be postioned so that the top or the bottom of the array ties in to the house at the level of the floor. This will ensure maximum structural strength.

4.6.4 Working on Roofs

1. Contractors installing solar systems in existing houses frequently encounter roofs that are not in good condition. It is always best to replace worn roofing materials prior to installing collectors. (It must be remembered, too, that solar panels are placed on southern roof elevations, those same areas of a roof most likely to deteriorate because of constant exposure to sunlight).

   If it appears that the roof surface will last for a few more years, a widely accepted approach is to patch in new roofing where the collectors will be placed. This will eliminate the need to remove the panels where the rest of the roof surface is eventually replaced.

2. The most commonly used roofing material today is the asphalt shingle. As asphalt shingles are thin and rugged, collector stand-offs and footings may be placed directly on top of the shingles, and mounted to the roof structure in an appropriate manner (see "Inspection Checklist").

   One primary concern in working with asphalt shingles is that major damage to a roof can occur either during very cold weather—when shingles become brittle and fragile—or in very hot weather, when the shingles become overly pliable and compressible. If work must be done during either of these extreme weather conditions, it is highly advisable to use a roof staging of some type.

3. Many other types of roofing materials now used, such as clay tiles, wood shake shingles, and slate, must be treated differently when installing solar panels. In these cases, the roofing material must be either cut or chipped away so that the bearing load of the collector array is fed directly to the roof structure. (Roof penetration must be very throughly sealed.) Because these materials are so fragile, great care must be taken when working with them.

4. Certain types of contemporary homes use rigid board insulation between sheathing and shingles. This insulation technique deserves special attention because the weight of collectors can compress the board over time, allowing the collector attachment points to weaken. One preferred approach is to locate precisely where the collector footings will be and cut away the shingles and insulation down to the sheathing. A wooden spacer of the same thickness as the insulation is then installed and the shingles covering the spacer replaced.

4.6.5 Piping Runs

1. As a general rule, in freezing climates piping should be run within the house wherever possible. Good insulation for exterior piping is available but large temperature differentials between heated transfer fluids and the ambient air may still lead to significant heat loss.

2. One good route for inside piping is through the backs of closets, cabinets, and stairwells. A careful inspection of the house will often show that closets on different levels are properly aligned to permit a straight run.

3. It is more difficult to run pipes in closed walls. Hidden fire stops, structural members, plumbing and electrical work can provide major obstructions. Additionally, it can be difficult to fit piping, properly insulated to R-4, into a closed wall constructed of 2x4 studs.

   If it is impossible to find closed spaces for the piping run, the solar loop piping can be boxed, in an attractive manner, into a corner of the house.

4. If outside piping is used, urethane having insulation with an ultraviolet inhibiting jacket or a specially painted elastomer insulation is recommended. In either case, the insulation can be painted to match the exterior of the home.
5. All exterior pipe runs must be mounted slightly off the siding material with the use of stand-offs. Popular stand-off options are F- and M-rings, unistrut channel, and rot resistant wood. Refer to the HUD Installation Guidelines (p. 41) for proper pipe hanging intervals.

6. If an outside piping run penetrates the foundation of the house, a PVC sleeve may be placed over the insulation and carefully mortared into the foundation wall. The interface of the insulation and sleeve should than be liberally coated with silicone sealant.

4.6.6 Storage

1. Whenever possible, storage vessels should be placed in a heated area.

2. Storage vessels should be placed as close as possible to auxiliary heating equipment to reduce line heat losses.

3. Storage vessels must have adequate space around them so as to be accessible for service.

4. Consideration must be given to the weight of the storage tank in relation to the load bearing capacity of the floor. For example, a typical stonelined 80-gal tank for a 3-panel water heater weighs approximately 450 lb dry and nearly 1200 lb when operational.

5. Attention must be given to door widths. Many solar storage tanks are 26 in. in diameter wide and may be difficult to fit through a narrow door or around a tight staircase.

4.6.7 Electrical Work

1. The most common electrical requirement for a solar system is the 110V supply to serve the controller and the pump. In most states the supply must be hard wired by a licensed electrician. In some areas, however, codes allow the use of an

electrical plug if the controller is within 6 ft of an outlet. Check with your local or state building authority for guidance.

2. Greater attention must be given to electrical backup elements if they are to be included in the solar storage system. Immersion elements typically require 220V service. Prior to the installation, installers should determine whether or not the incoming electrical service to the home can accommodate the addition of one or more elements.

4.7 REVIEW QUESTIONS

1. Give six considerations for the proper positioning of solar collectors on a roof.
2. Describe the different approaches to mounting collectors on slate as opposed to asphalt shingles.
3. Describe the proper method and materials to be used in insulating outside piping.
4. Give five considerations for placement of storage tanks.
5. What techniques should be used in mounting collectors over rigid board insulation?
6. Why is running solar piping through closed walls not a preferred technique?
7. Where is the first place to try to run solar piping from an attic to a basement?

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CHAPTER 5.0

DOMESTIC WATER HEATING SYSTEMS

According to the requirements of the RCS program, installers of renewable resource program measures need to be knowledgeable about the design, operation, installation, and maintenance of conventional hot water and space heating systems into which a solar device will be integrated. Inspectors will be required to check installations to ensure compliance with installation standards and satisfactory performance. To assist the installer and inspector, this chapter is included.

5.1 BASIC WATER HEATER SYSTEM COMPONENTS

A water heater is an appliance used to supply hot water for residential or commercial purposes other than space heating. The terms water heater system, domestic hot water system, and service hot water system are often used interchangeably because a water heating system consists of more than one component. The basic water heater system consists of four basic components:

- a heat generating source;
- heat transfer equipment;
- water supply piping or distribution system; and
- terminal water usage devices, such as plumbing fixtures and equipment that require hot water.

There are many different types of water heating systems in use today. However, they all have in common the basic components listed above and all are designed to supply hot water.

Before a discussion of the various types of water heater systems can begin, it is necessary to understand the basic water heater and how it operates. The material presented in this chapter presents information on gas-fired equipment and then points out the differences for oil-fired and electrically-operated equipment.

5.2 THE BASIC GAS-FIRED STORAGE TYPE WATER HEATER

Gas-fired water heaters installed for domestic use have for the most part, automatic storage. An automatic storage heater stores the water at an elevated temperature and automatically operates a heat source to maintain the desired water temperature. Domestic automatic storage water heaters range in size from about 5 to 120 gal.

A typical gas-fired storage heater is made up of many different components and systems. Typically they include:

- a combination thermostat and gas control valve,
- a gas burner,
- a heat exchanger, and
- a storage tank,

- An anode rod,
- A dip tube,
- A draft hood, and
- A venting system.

5.2.1 The Combination Thermostat and Gas Control Valve

The overall operation of the water heater is controlled by the gas control valve (Fig. 5-1). Typical components in a gas control valve include:

- Manual shut-off valve with pilot-gas-only position,
- Gas pressure regulator,
- Pilot safety valve,
- Thermostat, and
- High temperature limit.

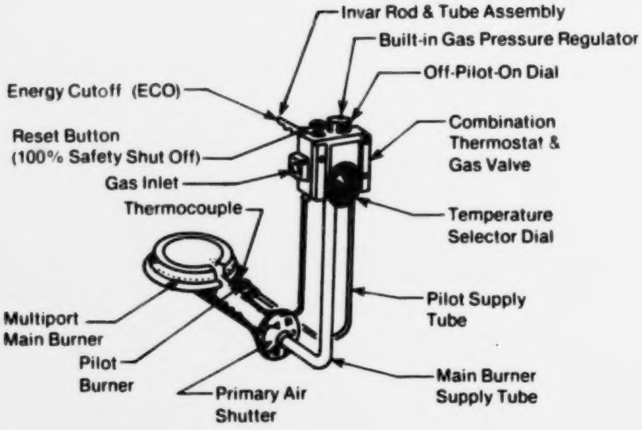

Invar Rod & Tube Assembly
Built-in Gas Pressure Regulator
Off-Pilot-On Dial
Energy Cutoff (ECO)
Reset Button (100% Safety Shut Off)
Gas Inlet
Thermocouple
Combination Thermostat & Gas Valve
Temperature Selector Dial
Pilot Supply Tube
Multiport Main Burner
Pilot Burner
Primary Air Shutter
Main Burner Supply Tube

Figure 5-1. Typical Gas Control Valve

The function of the manual shut-off valve is to allow manual shut off of the gas supply to just the main burner or to the main burner and pilot burner during periods when hot water is not required.

The function of the gas pressure regulator is to regulate the pressure of the gas at the burner and to keep it constant through any fluctuations of gas pressure in the supply piping. All new gas-fired equipment is required by national standards and codes to be equipped with a gas pressure regulator; however, some older equipment may not be equipped with a gas pressure regulator. On equipment fired with liquefied petroleum (LP) rather than natural gas, the gas pressure regulator is located at the LP storage tank rather than at the water heater.

The purpose of the pilot safety valve is to shut off all flow of gas to the main burner in the event the constant burning pilot light is extinguished for some reason. An automatic safety pilot system consists of a pilot burner, a thermocouple and a pilot safety valve. The pilot burner and thermocouple are located in the main burner compartment. In operation, the pilot flame at the pilot burner heats the thermocouple that, in turn, produces an electrical signal to energize the pilot safety valve and keep it open. If the pilot flame is extinguished, the thermocouple cools, thus decreasing the electrical signal, and the pilot safety valve closes. All appliances that burn LP gas, because LP gas is heavier than air, are required to have 100% shut-off pilot safety systems. This 100% shut-off means that all gas flow to both the pilot burner and main burner is shut off in the event of pilot outage. In non-100% shut-off systems, unburned gas is allowed to continue to flow through the pilot burner.

The purpose of the thermostat is to control the flow of gas to the main burner. Its operation is controlled by a thermostat sensing element, normally an invar rod and tube assembly, located inside the storage tank to sense water temperatures. The typical control valve has an adjustable selector dial that is normally calibrated from about 90°F on the low end to about 155°F on the high end. Newer control valves are also equipped with a high temperature limit, commonly called an ECO (energy cutoff), that acts to close the pilot safety valve if the water temperature inside the storage tank reaches about 180°F. If this limiting device operates, the water in the tank must be allowed to cool to about 120°F before the limit will reset and then the pilot manually relit before the water heater will operate again.

5.2.2 Gas Burner

The main gas burner controls the mixing of air and gas for proper combustion and determines the size, shape, and nature of the flame. It is located at the bottom of the heat exchanger, as illustrated in Fig. 5-2, so that the rising hot combustion gasses will flow up into the heat exchanger.

The two types of main burners normally used in domestic storage water heaters are shown in Fig. 5-3.

5.2.3 Heat Exchanger and Storage Tank

The typical heat exchanger or flue tube consists of a vertical tube extending through the storage tank. The flue tube is normally equipped with a flue baffle designed to slow down and swirl the hot combustion gasses to maximize heat transfer to the water.

Normally, the storage tank is constructed of steel and protected from corrosion by galvanizing, a coating of zinc on the inside surface of the tank. Newer water heater tanks are constructed with a glass lining or coating on the inside of the tank that gives longer life than galvanizing. All domestic storage type water tanks are also equipped with one to two inches of fiber glass insulation or foam wrapped around the outside of the storage tank to reduce standby heat loss from the water tank.

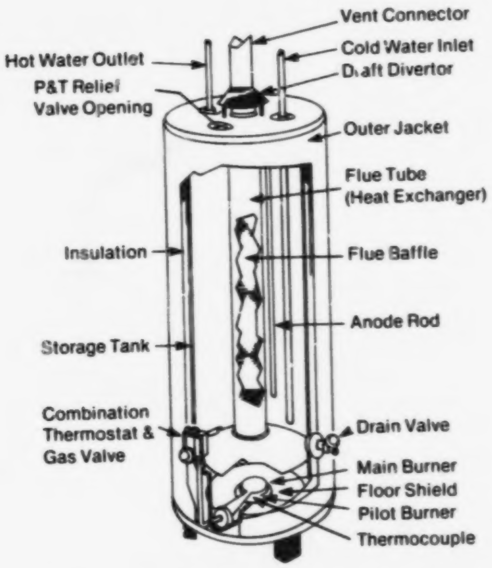

Vent Connector
Hot Water Outlet
Cold Water Inlet
Draft Divertor
P&T Relief Valve Opening
Outer Jacket
Flue Tube (Heat Exchanger)
Insulation
Flue Baffle
Anode Rod
Storage Tank
Combination Thermostat & Gas Valve
Drain Valve
Main Burner
Floor Shield
Pilot Burner
Thermocouple

Figure 5-2. Typical Gas-Fired Water Heater

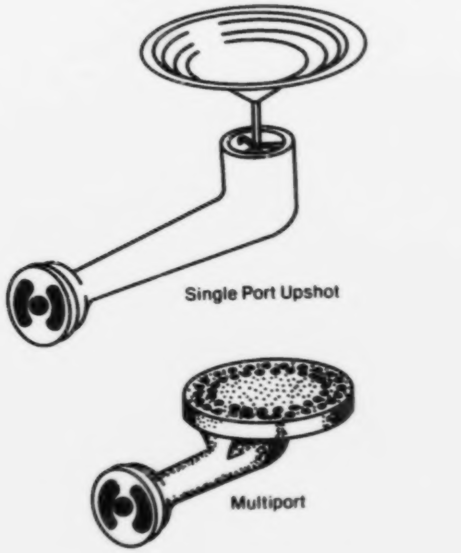

Single Port Upshot
Multiport

Figure 5-3. Typical Gas Water Heat Main Burner

5.2.4 Anode Rod

Most storage water heaters are equipped with an anode rod normally made of magnesium. The anode rod will corrode in preference to the steel tank, thereby helping to protect the tank from corrosion. The anode rod is located either in the top of the tank or is an integral part of the hot water outlet fitting (see Fig. 5-2).

5.2.5 Dip Tube

All water heaters, with the cold water inlet at the top of the tank, have a dip tube leading toward the bottom. Each dip tube has a small opening, called an antisiphon hole, located near the top end of the tube. This hole prevents the hot water in the tank from being siphoned out by an interruption in the cold water supply. The purpose of this tube is to deliver the incoming cold water through the stored water, to the bottom of the tank. Passing through the tube, the cold water does not mix with the hot water and is delivered to the area where it can be most rapidly heated, allowing hotter water near the top to be drawn first.

5.2.6 Draft Hood

The draft hood is located on the top of the water heater at the outlet of the flue tube (see Fig. 5-2). The hood prevents any change in the operation of the gas vent from affecting normal combustion within the heater. It also offers a ready means of escape for combustion products when there is no draft, a back draft, or actual stoppage within the vent itself.

Draft hood spillage is a sign of improper gas vent operation and means that combustion products are escaping into the building. A lighted match can be used to check vent operation (see Fig. 5-4). If the flame is drawn into the relief opening in the hood, the entering dilution air keeps the match burning. This shows good vent operation. If the flame is blown away or snuffed out, the vent system above the water heater should be checked for improper operation or blockage.

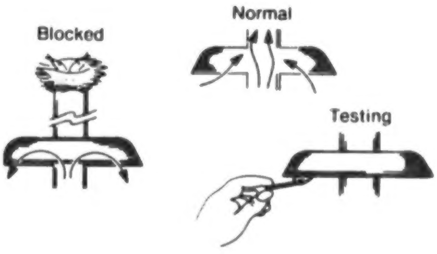


Figure 5-4. Checking Vent Operation

5.2.7 Venting System

The purpose of the venting system (Fig. 5-5) is to safely exhaust the products of combustion from the appliance to the outside atmosphere. Many different venting systems are used to vent products of combustion of gas appliances. Most systems can be classified as gravity vents and use the tendency of warm air to rise. This tendency for warm air to rise in a vent is commonly referred to as chimney action or venting action. The venting action of a system depends upon:

- The height of the system above the appliance—the greater the height, the greater the venting action.
- The diameter of the vent pipe—the greater the size, the greater the venting action.
- The temperature differences between the inlet of the venting system at the draft hood outlet and the outside atmosphere—the greater the difference, the greater the venting action.

Vent pipes are constructed of noncombustible, corrosion-resistant material of sufficient thickness to provide a reasonable life. Materials used include aluminum, steel, clay tile, and asbestos-cement. All-metal types employ double-wall construction enclosing an air space for insulation purposes. When installed with specific clearances, the heat insulating quality of this construction should be sufficient to avoid excessive temperatures near adjacent combustible materials. Normally, a vent pipe will specify directly on the vent the UL approved distance from combustibles. This vent is suitable for venting gas appliances with draft hoods and is frequently used in new construction because it is less expensive to install than a masonry chimney with liner.

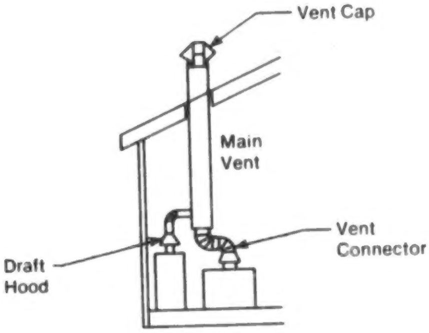


Figure 5-5. Typical Gas Vent System

The short section of vent pipe connecting the appliance to the main, or common section, of the venting system is called the vent connector. Normally, the vent connector is constructed of single-wall metal pipe.

The purpose of the vent cap is to keep rain, snow, and winds from entering the venting system.

All venting systems must be properly sized to match the connected appliances and installed in strict accordance with building code requirements.

5.3 DOMESTIC WATER HEATER TYPES

5.3.1 Automatic Storage Type

Gas-fired water heating equipment installed in residences mostly uses automatic storage. There are four basic designs:

- Center flue type
- Offset flue type
- External channel flue type
- Floating tank, external flue type

Of these the center flue is by far the most widely used. All four operate basically the same.

5.3.2 Operation

As was stated above, most domestic water heaters are of the internal or center flue design (see Fig. 5-6). The flue serves to conduct the products of combustion from the combustion chamber to the vent system. The internal flue is also part of the heat exchange surface and that portion immersed in the water could be more properly called the heat exchanger tube rather than the flue pipe or flue tube. It is common practice, however, to refer to the entire tube as the flue.

With the water heater main burner in operation, the flame and hot flue products heat the stored water. When the water temperature reaches the setting on the thermostatic control, the thermostat turns off the gas. The tank is now filled with hot water, ready for use.

Under everyday operating conditions, only a part of the hot water is drawn from the tank at any one time. As a result, cold water is introduced only in the lower part of the tank through the dip tube. The thermostatic control is usually located to sense water temperature in the lower part of the tank, so it acts to turn on the gas supply to reheat whenever cold water is in the tank during or after hot water draw. The thermostat shuts off the gas supply when the cold water has been heated, and the tank again is filled with hot water ready for the next usage.

During those periods in which there is no demand for hot water, the stored hot water loses some of its heat to the surrounding atmosphere through its insulation and jacket and out through the water heater venting system. This period without any water draw is called a standby condition and the heat losses that take place during this time are called standby losses. The bulk of standby losses takes place through the open water heater flue way. The thermostatic control is designed so that when the stored water temperature drops a predetermined amount (perhaps 15° to 20°F, depending on the thermostat differential), the thermostat again turns on the gas supply to reheat the water to the desired temperature. In other words, the thermostat maintains the temperature of the stored water between predetermined limits during standby periods, so that hot water will be readily available on demand.

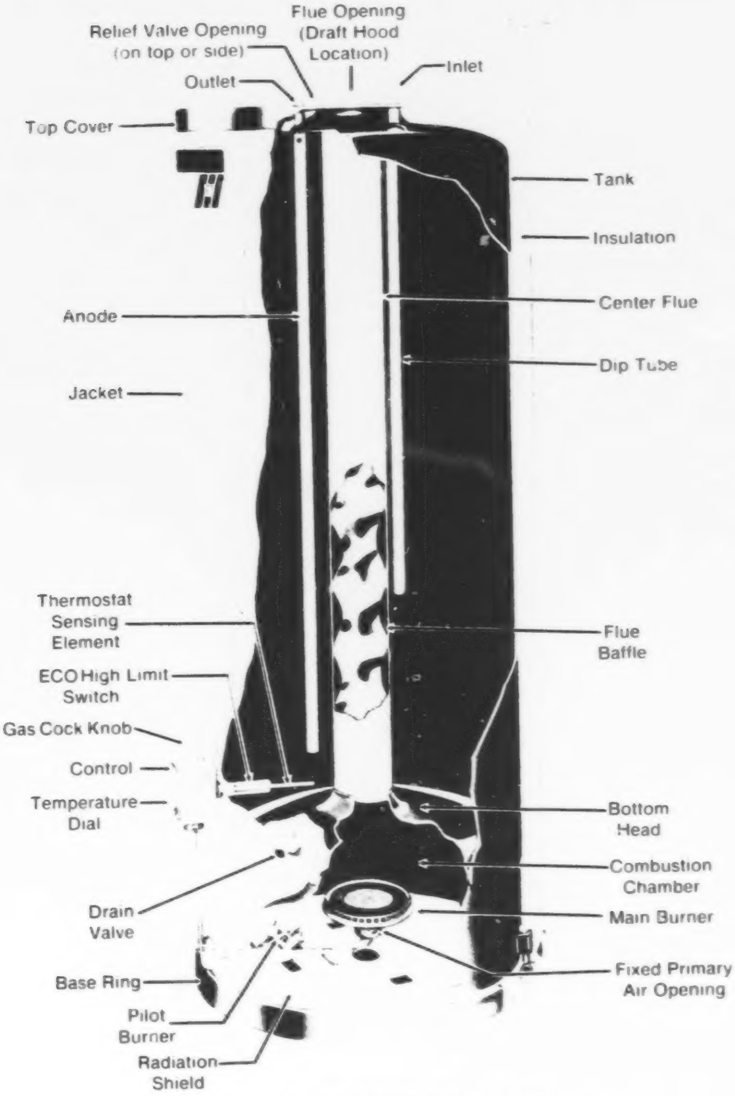

Relief Valve Opening
(on top or side)
Flue Opening
(Draft Hood
Location)
Inlet
Outlet
Top Cover
Tank
Insulation
Center Flue
Anode
Dip Tube
Jacket
Thermostat
Sensing
Element
Flue
Baffle
ECO High Limit
Switch
Gas Cock Knob
Control
Temperature
Dial
Bottom
Head
Combustion
Chamber
Drain
Valve
Main Burner
Fixed Primary
Air Opening
Base Ring
Pilot
Burner
Radiation
Shield

Figure 5-6. Typical Center Flue Water Heater

5.3.3 Instantaneous Water Heaters

Some water heaters do not store any appreciable quantity of water. Rather they heat the water as it is used. Instantaneous water heaters (Fig. 5-7) are defined by national standards as those having a rated input of at least 4,000 Btu/hr per gallon of self-stored water. Automatic control is obtained by water flow actuated controls, thermostatic controls, or a combination of the two. These heaters have the advantage of very compact size and virtually no standby loss since no storage tank is needed. The disadvantage is that the draw rate of hot water is relatively small compared to storage heaters. Instantaneous heaters are popular in Europe for domestic use. Few have been installed for domestic use in the United States, although they are becoming more popular now when used for back-up heat for solar domestic hot water.

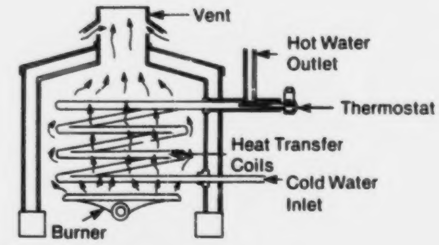


Figure 5-7. Instantaneous Water Heater

5.4 INSTALLATION CONSIDERATIONS

Because improper installation could result in user dissatisfaction, damaged equipment, and even bodily injury, it is important that sound installation practices be followed. In general, the instructions furnished with the water heater should be followed. Where these instructions do not conform to local codes, the local codes should be followed.

The typical water heater installation (Fig. 5-8) should include, as a minimum, the following:

- A temperature and pressure relief valve
- A shut-off valve on the cold water inlet pipe
- Unions on the cold and hot water pipes above the hot water heater
- Location close to a floor drain
- Proper ventilation (for combustion units)
- Gas shut-off valve (for combustion units)

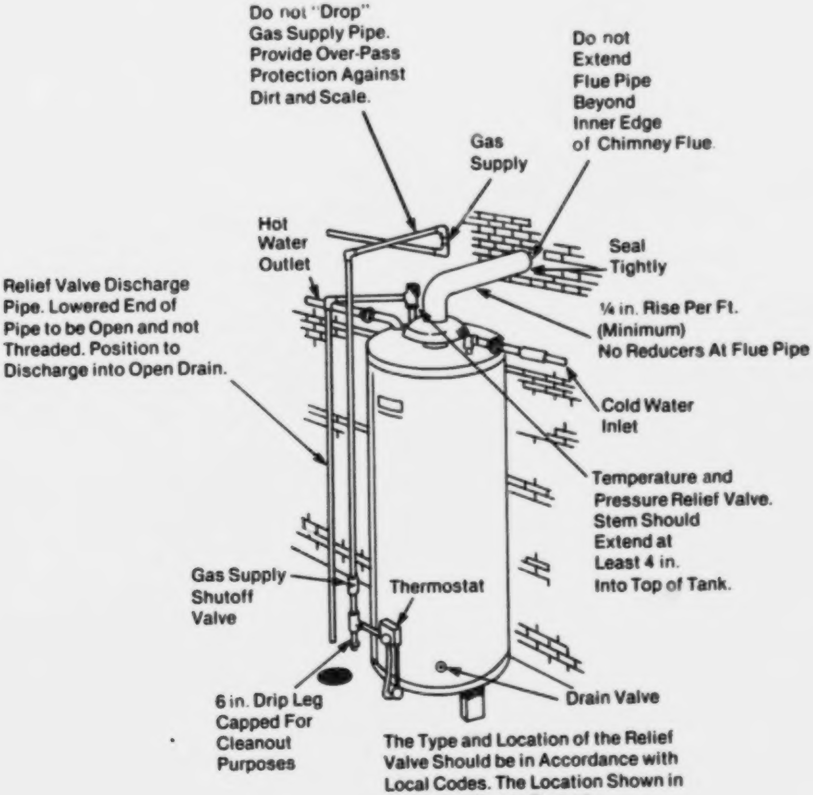
5.5 THE OIL-FIRED STORAGE TYPE WATER HEATER

5.5.1 Uses

Water heaters that use oil burners to combust oil (Fig. 5-9) are very similar to water heaters that use natural gas burners. The main difference is in the burner itself with slight differences found in the control system and venting system.

Oil burners burning in the range of 1/2 to 1 gal of fuel per hour are generally used in domestic oil-fired hot water heaters.

The great majority of domestic oil-fired water heaters utilize the high pressure atomizing gun burner. Substantial numbers of other types of oil burners, described below, are still in operation but only a few of these other types are currently in production.


Do not "Drop" Gas Supply Pipe. Provide Over-Pass Protection Against Dirt and Scale.
Do not Extend Flue Pipe Beyond Inner Edge of Chimney Flue.
Gas Supply
Hot Water Outlet
Seal Tightly
Relief Valve Discharge Pipe. Lowered End of Pipe to be Open and not Threaded. Position to Discharge into Open Drain.
¼ in. Rise Per Ft. (Minimum) No Reducers At Flue Pipe
Cold Water Inlet
Temperature and Pressure Relief Valve. Stem Should Extend at Least 4 in. Into Top of Tank.
Gas Supply Shutoff Valve
Thermostat
Drain Valve
6 in. Drip Leg Capped For Cleanout Purposes

The Type and Location of the Relief Valve Should be in Accordance with Local Codes. The Location Shown in the Illustration is Typical.

Figure 5-8. Typical Water Heater Installation

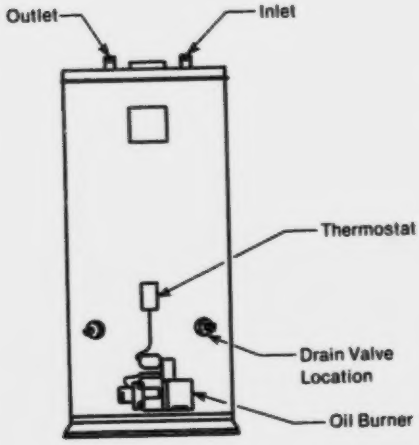

Outlet
Inlet
Thermostat
Drain Valve Location
Oil Burner

Figure 5-9. Typical Oil-Fired Water Heater

5.5.2 The High-Pressure Atomizing Type Gun Burner

This burner (Figs.5-10, 5-11) supplies oil to the atomizing nozzle at 100-300 psi. A blower is used to supply the air for combustion and a damper or other adjustable means regulates the air supply at the burner.

Ignition is usually established by a high-voltage electric spark that may be intermittent. Intermittent ignition means that the electric spark is energized, or on, during the entire time that the oil burner is operating. Interrupted ignition means that the electric spark is energized only at the beginning of the ignition cycle and is de-energized, or turned off, once the oil burner is ignited.

Typically, this type of oil burner depends on chimney action for proper operation. For this reason, a draft hood is not used. Instead, a barometric draft regulator is used to serve the same function as a draft hood and also to control the draft through the heat exchangers to ensure proper combustion.

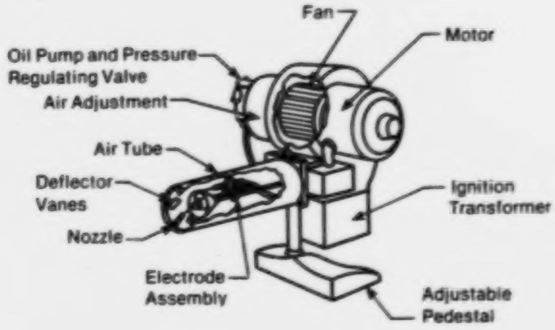

Fan
Motor
Oil Pump and Pressure Regulating Valve
Air Adjustment
Air Tube
Deflector Vanes
Nozzle
Electrode Assembly
Ignition Transformer
Adjustable Pedestal

Figure 5-10. High-Pressure Atomizing Oil Burner

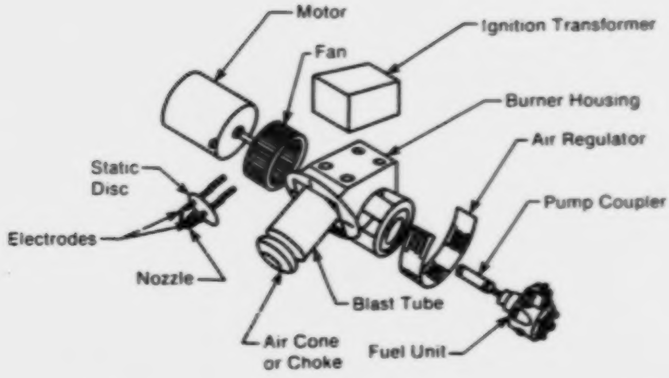

Motor
Ignition Transformer
Fan
Burner Housing
Air Regulator
Static Disc
Pump Coupler
Electrodes
Nozzle
Blast Tube
Air Cone or Choke
Fuel Unit

Figure 5-11. Details of a High-Pressure Atomizing Oil Burner

Recent trends in high-pressure atomizing gun burner design include widespread application of retention heads and burner motors operating at 3450 rpm instead of 1725 rpm. The retention head assists combustion by providing better air/oil mixing for proper combustion. The use of 3450-rpm motors has resulted in a more compact burner having equal capacity, and one that reportedly has more tolerance for varying draft conditions in the heat exchanger.

5.5.3 The Pressure Atomizing Forced Draft Gun Burner

This burner has a basic construction similar to that of the gun burner except that this burner generates its own draft conditions within the heat exchanger and does not depend on chimney action for proper combustion. For this reason, a draft hood or barometric draft regulator normally is not required.

5.5.4 The Low-Pressure Atomizing Gun Burner

This burner differs from the high-pressure type mainly in using air at low pressure to atomize the oil. Atomizing air is supplied to the nozzle in the range of 1 to 15 psi, usually by means of a special pump design. Fuel oil and air are delivered by this pump through separate lines to the nozzle where atomizing takes place.

5.5.5 The Pressure Atomizing Induced Draft Burner

This burner uses the same oil pump, nozzle, and ignition as the high-pressure atomizing gun burner. The basic difference in construction is the location of the blower fan downstream of the heat exchanger.

5.5.6 Oil Storage

One other important difference between oil burning equipment and equipment that uses natural gas as the fuel is that oil must be stored at the home in storage tanks. These tanks may be located inside the home, as shown in Fig. 5-12, or outside. Normally, inside tanks are preferred because of ease of installation, service, and repair. Also, inside tanks usually allow gravity oil flow to the burner which could eliminate the need for an additional oil pump. However, most current building codes require the use of a pressurized oil system and prohibit the use of gravity type oil systems. Also, most fire codes require outside tanks to minimize fire hazards.

5.5.7 Special Oil Burner Controls

In addition to the normal temperature controls used with gas-fired equipment, oil burning equipment also requires the use of special controls to monitor the oil combustion process. These controls function to shut off the flow of oil in the event of:

- Ignition Failure—This control can be located in the stack or flue passageway exiting the oil equipment and is sometimes called a stack relay.
- Combustion Air Fan Failure—Normally located on the burner or in the combustion chamber.
- Low Fuel Oil Pressure.

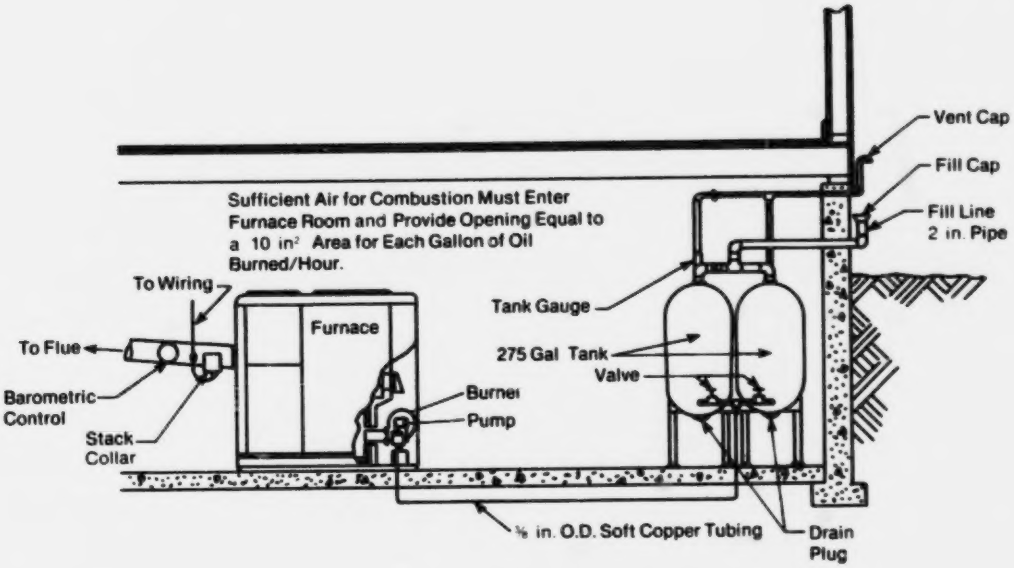

Vent Cap
Fill Cap
Fill Line
2 in. Pipe
Sufficient Air for Combustion Must Enter Furnace Room and Provide Opening Equal to a 10 in² Area for Each Gallon of Oil Burned/Hour.
To Wiring
Furnace
Tank Gauge
275 Gal Tank
Valve
To Flue
Barometric Control
Stack Collar
Burner
Pump
⅜ in. O.D. Soft Copper Tubing
Drain Plug

Figure 5-12. Typical Installation of Oil Burning Equipment

These special controls do not affect the normal operation of the heating equipment and must only be adjusted by qualified oil burner servicemen.

5.6 THE ELECTRIC TYPE WATER HEATER

Automatic electric storage water heaters as shown in Fig. 5-13 may range from 5 to 120 gal tank capacity. In contrast to the gas-fired water heater, the tank is designed without a flue passage since the removal of flue products is no longer necessary. Also, instead of a gas or oil burner, the electric water heater uses one or more electric resistance heating elements. These elements operate similarly to the elements found on an electric range.

Water heaters of 30 to 120 gal tank capacity generally have a primary resistance heating element near the top and possibly a secondary element located near the bottom of the tank. Minimum wattage rating of two element heaters are based on about 30 W/gal of tank capacity for the upper element and about 20 W/gal for the lower element. Fast recovery heaters may be designed for as much as 100 W or more in each element per gallon of tank capacity. In twin element heaters, the thermostats that control the elements are usually interlocked so that the primary and secondary heating elements cannot operate simultaneously.

A variation of the gas instantaneous water heater is the electric instantaneous water heater, or point-of-use electric water heater. The electric point-of-use water heater operates in the same manner as the gas instantaneous heater discussed previously except that it uses an electric heating element rather than a gas or oil burner for the heat source. The electric point-of-use heater is designed to deliver small water volumes, normally less than 30 gal/min, and is installed at each location where hot water is required.

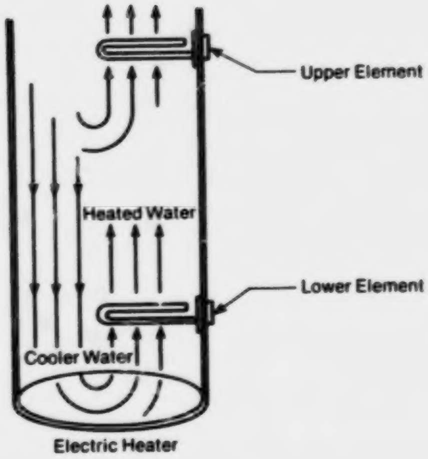


Figure 5-13. Typical Domestic Electric Hot Water Heater

5.7 MAINTENANCE

For any water heater to operate safely and at optimum efficiency, periodic maintenance must be performed on the system. The heart of any storage water heater is the tank. To assure long life and efficiency, the water heater tank should have some water drained periodically to help prevent sediment buildup in the tank bottom. The best way to accomplish this is to open the drain valve once a month and allow water to drain until it flows clean. In some water areas, the sediment buildup inside the tank might be so severe that it is not easily removed following this method. An indication of excessive sediment, or mineral deposits, is a rumbling or boiling noise during main burner operation. To dissolve and remove these more stubborn mineral deposits, it may be necessary to use a commercial delimer. The cleaning instructions furnished with the delimer should be carefully followed to ensure proper cleaning.

5.8 SYSTEM DEGRADATION

As with any heating system, a water heating system will degrade naturally over time and this will result in a decrease of operating efficiency. This normal degradation may be slowed down by following a routine periodic maintenance program but cannot be eliminated.

Perhaps the biggest enemy of a water heater is corrosion from within the tank or coil and external to the tank in the flue tube and venting system. As was pointed out previously, the function of the anode is to protect the tank from corrosion. However, once the anode is completely corroded, it can no longer protect the inside surface of the tank and tank corrosion will begin. Eventually, small holes will develop in the tank with the only correction being to replace the water heater.

Corrosion external to the tank is the result of condensation. Condensation in the flue tube or vent is the result of water vapor in the combustion gasses being chilled below the dew point. The dew point is that temperature at which the water vapor turns into a liquid (condenses). This condition is similar to the condensation which occurs on the outside of a cold glass on a hot, humid day. Chilling of the combustion gasses takes place when excessive heat loss occurs through the walls of the flue tube and vent. The amount of condensate is proportionate to the length of the vent pipe with the shorter run producing the least or no condensate. The use of double-wall vent material is another possible solution to the condensation problem.

Whenever the water heater is filled with cold water, there usually will be a certain amount of condensation formed on the cooler tank surface. Drops of water may fall on the floor shield or the hot burner surfaces producing a sizzling sound. This is normal and will disappear as the water in the tank becomes heated.

It is important to recognize the reasons for condensation and remember that condensation outside the heater is the fault of the vent system. Condensation within the heater may merely indicate cold inlet water temperature.

Other factors that can cause degradation of a water heating system are:

- Scale-forming water or hard water. About 85% of the United States is served with water containing concentrations of dissolved minerals sufficient to form lime scale inside the tank and decrease efficiency.
- The temperature to which the water is heated. Scale formation can be reduced by adjusting the water heater thermostat to a lower setting. For example, the formation rate of scale at 180°F water temperature is about seven times greater than at 140°F.
- High water pressures. Excessive city water pressures can contribute to equipment damage.
- Thermal expansion. Water expands as it is heated. If the water heater is operated without a relief valve or with a faulty relief valve, excessive pressure could be generated inside the water tank and water distribution system, which could cause serious damage.

5.9 RESIDENTIAL SPACE HEATING SYSTEM

The purpose of a heating system is to provide human comfort when outside weather conditions are too cool for comfort. Human comfort results when the rate of heat loss from the body is in correct balance with the individual's psychological and physical needs.

5.9.1 Body Heat Loss

- Radiation—When the body is surrounded by surfaces that are cooler than normal body temperatures, heat will be transferred from the warm body to the cooler surface by radiation. For example, when sitting next to a window on a cold day, the glass surface temperature might be as low as 40°F. That surface will act as an absorber of the skin's radiant heat, resulting in the perception that heat is being lost from the body very rapidly. Sometimes, radiant heat losses are sensed as cool drafts.
- Convection—When the air surrounding a body is less than exposed skin temperature, it will pick up heat or transfer heat from the body to the air as it passes over the body and carry it away. The faster the air moves over the body, the faster the rate of heat loss.

- Evaporation—Body heat is consumed, or lost, in the process of evaporation. This is known as latent heat, which is the heat required to change the form, or state, of a substance without changing its temperature level. In cold weather, some moisture is being evaporated from the body surfaces and from the lungs as you breathe, chilling you.

5.9.2 Living Environment

Some living environment conditions that affect human comfort are:

- Air Temperature—Body heat loss through convection to the surrounding atmosphere is dependent on the air temperatures.
- Air Velocity—Body heat loss through both convection and evaporation is dependent on surrounding air motion or velocity.
- Temperature of Surrounding Surfaces—Body heat loss through radiation is dependent on the temperature of the surrounding surfaces, such as window glass and walls.
- Relative Humidity—Relative humidity is an expression of the amount of water vapor contained in the air compared to the maximum amount that it is capable of holding at that air temperature. When the relative humidity, or moisture content, of the surrounding air increases, its ability to evaporate moisture decreases. So heat loss from the body by evaporation decreases as the air becomes more moist.

Some other factors that affect human comfort are the degrees of smoke, odors, pollen, and dust in the air. To maintain acceptable levels of comfort, it may be necessary to provide adequate fresh air and air filtration systems in the home.

5.9.3 Heat Transfer Methods

A heating system is designed to offset body heat losses by introducing heat into the home and reducing or eliminating body heat losses through radiation, convection, and evaporation. People may be made comfortable in a house by any one or combination of the following methods:

- Radiation—Heating the surrounding surfaces to a temperature equal to or greater than skin temperature.
- Convection—Circulating warm air inside the living environment.
- Conduction—Allowing furniture and other objects to warm up to the air temperature.

In summary, some important points to keep in mind are:

- The direction of heat flow is from the warm side, or warm object, to the cold side, or cold object.
- The rate of heat flow depends on the difference in temperature between the warm side and the cold side.

- To ensure human comfort, excessive body heat losses must be offset by introducing heat into the living environment in the correct proportions of temperature and moisture during cold outdoor weather conditions.

5.9.4 Basic Heating System Components

As was previously discussed, the purpose of a heating system is to provide human comfort when outside weather conditions are too cool for human comfort. As the term space heating system implies, a heating system is comprised of a number of different components or subsystems. A basic heating system includes as a minimum:

- A heat generating unit, such as a furnace, to produce heat. The generating heat unit may operate on natural gas, liquefied petroleum gas such as propane, oil, solid fuel such as wood or coal, or electricity.
- A heat distribution system to move the generated heat from the heat producing unit to the areas inside the home where it is required.
- A control system, such as a room thermostat, to maintain the correct temperature level within the home and to tell the heat producing unit when to produce heat.

A fourth, less obvious, component of the heating system is the human occupant who defines the conditions of comfort for the control system.

Many different types of heating systems are used today. However, they all have in common the basic components listed above and all are designed to provide comfort heating. Before a discussion of the various types of heating systems can begin, it is necessary to understand the basic heat producing appliance and how it operates. The material presented in this text will present the operation and components of gas-fired equipment and then point out the differences for oil-fired and electrically operated equipment.

5.10 THE BASIC GAS-FIRED HEATING APPLIANCE

A gas-fired heating appliance is made up of many different components and systems. These include:

- A main gas manifold assembly
- A gas burner
- A heat exchanger
- A draft hood
- A venting system
- A temperature control system

5.10.1 Main Gas Manifold Assembly

Gas-fired equipment is equipped with a main gas manifold assembly that connects to the gas supply piping (Fig. 5-14). The main gas manifold includes all the gas controls and distributes the gas to the main burners.

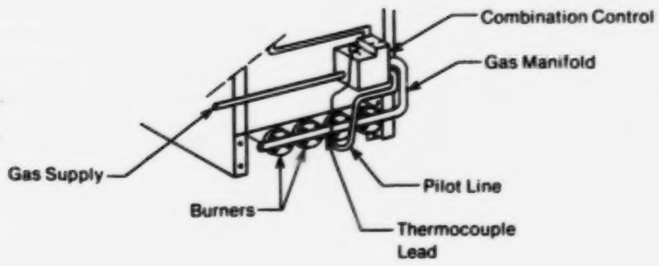

Combination Control
Gas Manifold
Gas Supply
Pilot Line
Burners
Thermocouple Lead

Figure 5-14. Gas Burner and Main Gas Manifold Assembly

A manual shut-off valve is generally located between the gas controls and the supply piping. This allows shut-off of the gas supply for servicing the appliance without shutting off the gas supply to other appliances located in the home. Generally, the manual shut-off valve should be located as close to the appliance as possible.

The main gas manifold normally includes a gas pressure regulator, an automatic pilot safety valve and a main gas valve. On modern equipment, a combination gas valve replaces all of these devices and includes all required gas controls in one body or housing as discussed under "water heating."

5.10.2 The Main Gas Burner

The main gas burner (Fig. 5-15) controls the mixing of air and gas for proper combustion and determines the size, shape, and nature of the flame. The main gas burner is located at the bottom of the heat exchanger so that the rising hot combustion gasses will flow up into the heat exchanger. The operation of the main burner is dependent on the flow of gas and ignition by the pilot burner flame.

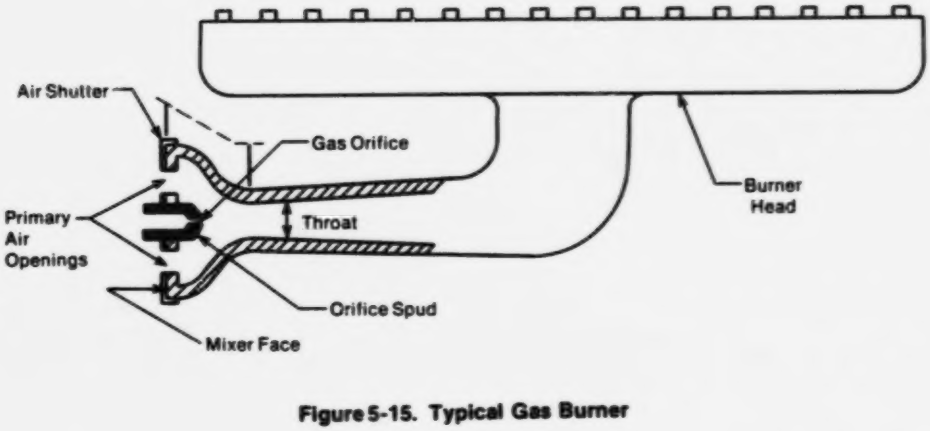

Air Shutter
Gas Orifice
Burner Head
Primary Air Openings
Throat
Orifice Spud
Mixer Face

Figure 5-15. Typical Gas Burner

Located at the inlet to the main gas burner is the orifice. The purpose of the orifice is to control the quantity of gas to the main burner for combustion. The amount of gas delivered to be burned at the main burner may be controlled by increasing or decreasing the size of the opening in the orifice. It is important that the size of the opening be correct so that the gas-fired heating equipment burns the correct amount of gas. Otherwise serious combustion problems, such as delayed ignition and/or production of carbon monoxide may result.

5.10.3 The Heat Exchanger

The heat exchanger (Fig. 5-16) is located directly above the main burner or burners so that the rising hot combustion gasses will evenly heat the surfaces of the heat exchanger. The purpose of the heat exchanger is to transfer the heat, through conduction, from the hot combustion gasses to an air stream, water, or directly to the room in some cases.

It is important to note that the heat exchanger keeps the combustion gasses from mixing with normal room air and provides a path for the combustion gasses out of the heating appliance. If the heat exchanger were to allow the combustion gasses to mix with or enter circulated room air, excessive levels of moisture could result and, more importantly, dangerous levels of toxic gasses could build up inside the home.

5.10.4. The Draft Hood

The draft hood, or draft diverter, is located at the outlet of the heat exchanger and is normally a part of the flue outlet of the appliance. A draft hood may be of the built-in or external type as shown in Fig. 5-17.

The purpose of a draft hood is to:

- Provide a path for the relief (exit) of the combustion gases in the event the venting system becomes stopped.
- Prevent a back draft, or reverse air flow in the vent system, from entering the appliance. A reverse air flow in the vent system could be caused by abnormal wind velocities blowing on the vent outlet located outside.
- Neutralize the effect of the venting system upon the operation of the appliance. Outside weather conditions such as temperature changes and wind conditions will cause the draft in the venting system to increase or decrease. These changing conditions must be neutralized to ensure proper combustion.

During normal operation, the combustion gasses leave the appliance at the flue outlet and mix with room air (dilution air), which enters the draft hood through the relief opening. After the combustion gasses are mixed with the diluted air, they are channeled into the venting system and directed to the outside atmosphere, the operation being as described in the water heating section.

5.10.5 The Temperature Control System

The purpose of the temperature control system is to control the operation of the appliance depending on the level of temperature existing in different locations in the heating

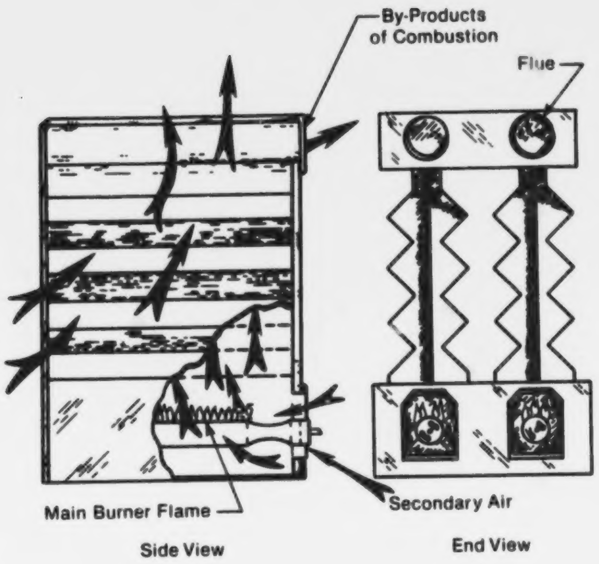

By-Products of Combustion
Flue
Main Burner Flame
Secondary Air
Side View
End View

Figure 5-16. Typical Heat Exchanger

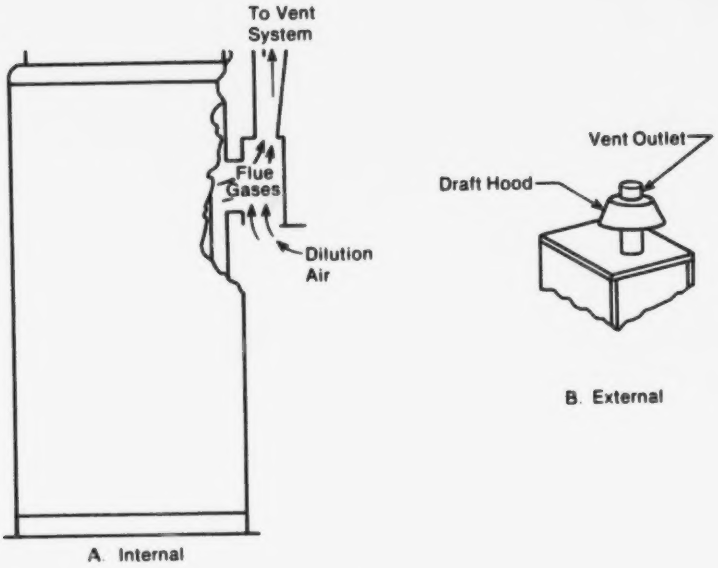

To Vent System
Flue Gases
Dilution Air
A. Internal
Vent Outlet
Draft Hood
B. External

Figure 5-17. Draft Hood

system. Normally, temperature controls found in a temperature control system may be classified as either operating controls or safety controls. Controls that cause the appliance to operate for its intended use, for example a room thermostat, are called operating controls. Controls that function to prevent a hazardous operation are called safety controls. Sometimes one control performs both functions.

Operating controls include:

- Room Thermostat—Thermostats regulate the operation of the heating appliance by causing the main gas valve to open and close, thus controlling the flow of fuel to the main burner.
- Fan Thermostats or Switches—Fan switches are located inside the appliance and cause the blower to operate after a sufficient amount of heat has accumulated in the heat exchanger to provide warm air to the heating system. Fan switches also keep the blower on after the gas burner shuts off long enough to ensure that most of the useful heat has been removed from the heat exchanger.

Safety controls include:

- High Limit—A high limit is a switch located inside the appliance and acts to shut off the fuel supply in the event the appliance overheats for some reason.
- Pilot Safety Control Systems—Pilot safety control systems shut off the supply of fuel in the event the pilot flame is extinguished.

Operating controls should be adjusted for greatest comfort and optimum operation of the system. Safety controls must be adjusted only by qualified servicemen.

Operating controls include:

- Room Thermostat—Thermostats regulate the operation of the heating appliance by causing the main gas valve to open and close, thus controlling the flow of fuel to the main burner.
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- High Limit—A high limit is a switch located inside the appliance and acts to shut off the fuel supply in the event the appliance overheats for some reason.
- Pilot Safety Control Systems—Pilot safety control systems shuts off the supply of fuel in the event the pilot flame is extinguished.

Operating controls should be adjusted for greatest comfort and optimum operation of the system. Safety controls must be adjusted only by qualified servicemen and in strict accordance with the heating appliance manufacturer's instructions to ensure safe operation of the equipment.

5.11 SPACE HEATING SYSTEMS

Basically, there are two different categories of heating systems in use today: decentralized systems and centralized systems. With the intention of this workbook being to provide systems background for potential interconnection with active solar systems, only centralized systems with forced air or water delivery will be considered.

5.11.1 Centralized Systems

Centralized heating systems use self-contained heating equipment centrally located within the home. Centralized systems are divided into two general classifications:

- Warm air systems
- Hydronic systems

Central heating systems are constructed for the purpose of heating a fluid (air, water, or steam) commonly conveyed through ducts (air) or pipes (water or steam) to the space being heated. Combustion takes place in a metal-walled heat exchanger and the fluid is circulated over the surfaces of the heat exchanger. The products of combustion are conveyed through a venting system to the outdoors.

Warm Air Furnaces

Furnaces that heat air that is then circulated throughout the dwelling are commonly referred to as warm air furnaces (Fig. 5-18) and are generally the most popular type of central heating equipment in use today. Warm air furnaces used in residences are usually under 250,000 Btu/hr input and may be forced air or gravity. Due to the poor efficiency potential of an active solar/gravity interconnection, gravity systems will not be discussed further.

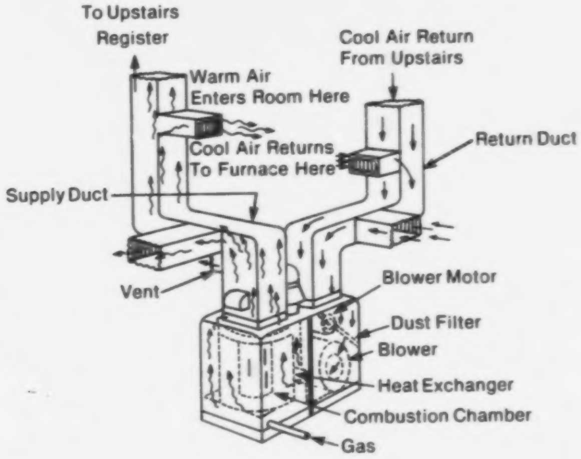
To Upstairs Register
Cool Air Return From Upstairs
Warm Air Enters Room Here
Return Duct
Cool Air Returns To Furnace Here
Supply Duct
Vent
Blower Motor
Dust Filter
Blower
Heat Exchanger
Combustion Chamber
Gas

Figure 5-18. Forced Warm Air System

Forced Air-Furnaces. Forced air furnaces (Fig. 5-19) are equipped with blowers to circulate the air to be heated through the furnace enclosure, over the heat exchanger, and through the duct work distribution system. A forced-air furnace has the following construction features: an ignition device and a shut-off feature. The ignition device is provided to ignite the main burner when there is a call for heat. The shut-off feature causes shutoff of the main burner gas supply in case the ignition system fails. A common device of this latter type employs a standing pilot that heats a thermocouple. Upon failure of the pilot flame, the thermocouple cools. The absence of anelectrical signal from the unheated thermocouple results in gas shutoff. An automatic gas valve opens and closes the gas supply to the main burner in response to the signal of the thermostat and the safety controls.

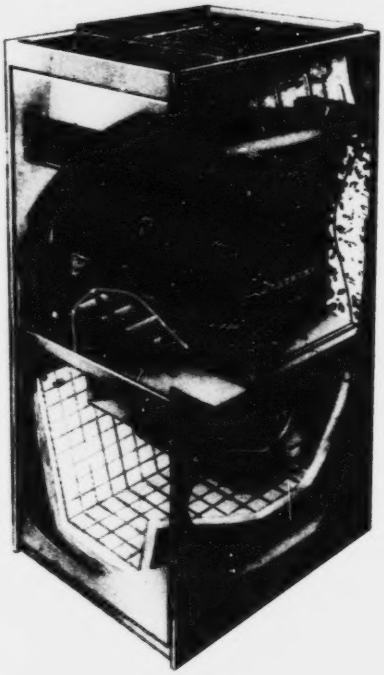

Figure 5-19. Typical Forced-Air Furnace

A thermostat, usually located in the area to be heated, automatically operates the furnace to maintain the desired temperature in the heated space. The thermostat should be mounted on an inside wall away from drafts, sunshine, cooking appliances, or other sources of heat. Holes in the wall behind the thermostat should be sealed to prevent drafts that may affect the thermostat.

Most thermostats have bimetal thermally-activated elements. A magnet is used in some thermostats to cause a snap action when the contact points open or close. This helps to avoid burning of the contact points or chatter of an electric gas-control valve. Some thermostats use enclosed mercury switches tripped by a bimetal element to make and break the electric control circuit.

When the thermostat shuts off the burner, there is a substantial amount of heat in the furnace and the ductwork. Since the blower continues to run after the burner is shut off, this heat may raise the temperature of the dwelling past the upper control point of the thermostat, especially in mild weather. To avoid this temperature overshoot, the thermostat contains a device called a heat anticipator. This is a small electric resistance heater that warms the bimetal element slightly when current is flowing through the control circuit. This small amount of heat causes the thermostat contacts to open before the upper temperature control point is reached. The residual heat in the furnace then warms the room to just the right temperature. A selection of heater elements is available to match the current draw of different furnace control valves. Some thermostats are provided with adjustable heat anticipators.

A limit control placed in the outgoing circulating air stream acts to shut down the burner gas supply if the circulating air temperature becomes too high. A fan switch controls the blower operation. This switch causes the blower to operate when the circulating air temperature rises to a preset value after the burner is turned on. After the thermostat shuts off the gas, the switch will stay closed and the blower will continue to operate until the circulating air temperature reaches a set low temperature. This temperature is selected to draw off as much heat from the heat exchanger as possible and yet not cause the circulating air to feel uncomfortably cool to house occupants. Often the fan and the limit switches are incorporated into one housing and are sometimes operated by the same thermostatic element. The actuating elements of the controls may be located in the warm air plenum, the duct, or within the furnace cabinet at some point in the circulating air stream.

Combustion occurs in the combustion chamber, which is a space large enough for the fuel requirements and is usually part of the heat exchanger. In addition, the heat exchanger has secondary flue passageways to bring the hot flue gas into contact with the heat exchanger surfaces.

Heat exchangers usually take one of two forms. In some furnaces a single combustion chamber is used, usually cylindrical in shape (Fig. 5-20), with the extended flue passages either adjacent to the combustion chamber or encircling it. These furnaces have a single burner. A sectional or clam shell furnace has a series of sections connected at the bottom and connected with a common flue gas breeching at the top. This type of furnace has an individual burner under each heat exchanger section. Those that use a single pilot burner to ignite all burners, employ a cross-over tube between the sections to carry the ignition flame from burner to burner.

Several different configurations of forced-air furnaces are manufactured for different applications. The upflow (high-boy) furnace (Fig. 5-21) has the blower at the bottom. Air enters at the side or bottom and leaves at the top. These furnaces may be used in utility rooms, or in basements with the return air ducted to the furnace air inlet.

The basement or low boy furnace (Fig. 5-22) is a variation of the upflow furnace and requires less headroom. The blower is located alongside the heat exchanger at the bottom.

In downflow or counter-flow furnaces (Fig. 5-23), the blower is located at the top and air is discharged vertically at the bottom. This type furnace is used with a perimeter heating system in a house without a basement. A special base may be necessary if the furnace is installed on a combustible floor. A secondary limit control at the top of the furnace interrupts burner operation in case of blower failure.

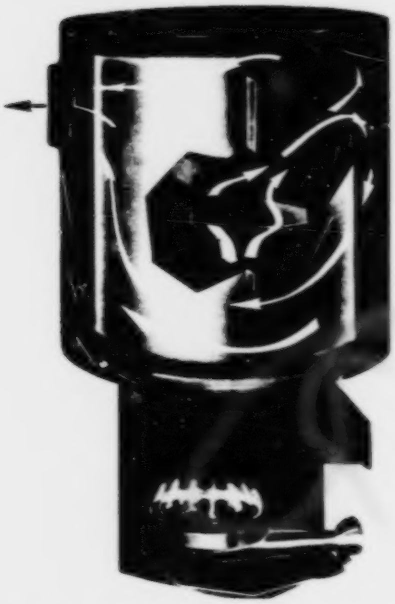

Figure 5-20. Cylindrical Type Heat Exchanger

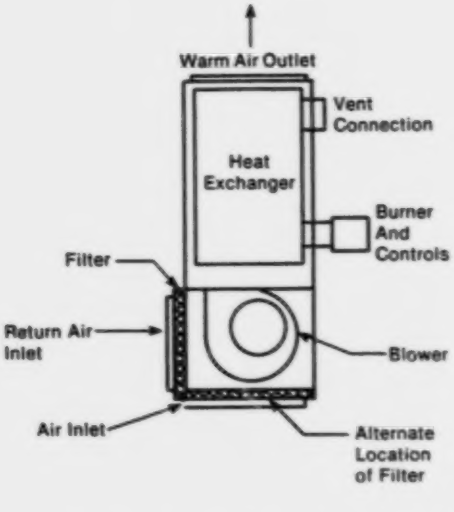
Warm Air Outlet
Vent Connection
Heat Exchanger
Burner And Controls
Filter
Return Air Inlet
Blower
Air Inlet
Alternate Location of Filter

Figure 5-21. High-Boy or Upflow Forced-Air Furnace

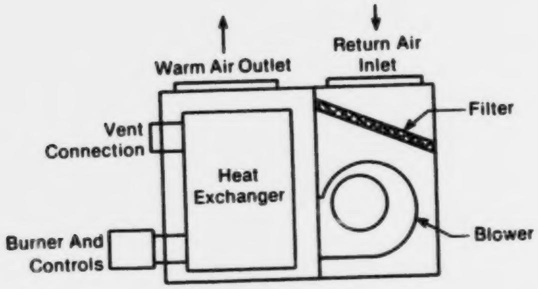
Warm Air Outlet
Return Air Inlet
Filter
Vent Connection
Heat Exchanger
Blower
Burner And Controls

Figure 5-22. Low-Boy Forced-Air Furnace

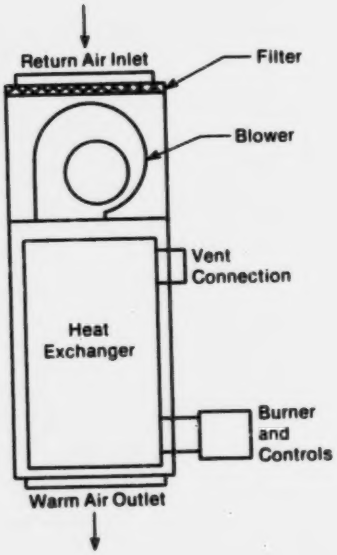
Return Air Inlet
Filter
Blower
Vent Connection
Heat Exchanger
Burner and Controls
Warm Air Outlet

Figure 5-23. Downflow or Counter-Flow Forced-Air Furnace

The horizontal furnace has the blower located alongside the heat exchanger, which results in a low profile (Fig. 5-24). The air travels through the furnace in a horizontal direction. These furnaces are used in locations with limited headroom such as attics, crawl spaces, below floors, or suspended below ceilings. Often they are designed to be convertible as to direction of flow. It can be right to left or left to right. Horizontal furnaces must have a limit switch at each end in case the warm air begins to flow by gravity in the wrong direction before the fan turns on.

Forced Air Distribution Systems. The level of comfort obtained in a home is largely determined by the type of distribution system used. The performance of the distribution system is, in turn, dependent on the location of the warm air supply outlets, and to a lesser extent, the location of the return air grilles. Warm air supply outlets, as well as return air grilles, may be located either at ceiling level (high) or at floor level (low).

Generally, the best location for warm air supply outlets is that which provides a vertical air pattern to blanket cold areas, such as outside walls and windows, and to counteract cold drafts. This method of introducing warm air to blanket outside walls and windows is called perimeter heating.

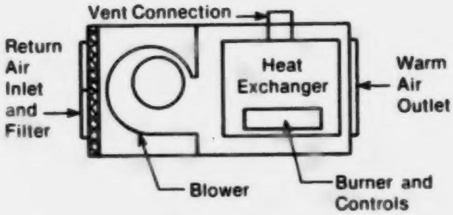

Figure 5-24. Horizontal Forced-Air Furnace

The two most common types of perimeter systems are the perimeter radial system (Fig. 5-25) and the perimeter extended plenum system (Fig. 5-26). In the radial system the air distribution system consists of individual ducts running spokewise beneath the floor from the plenum chamber or a centrally located furnace to each perimeter warm air outlet. In buildings with slab floors, the warm ducts may be embedded in the concrete floor or be located in the attic. In buildings with crawl spaces the ducts are generally located in the crawl space, and, to ensure warm floors, one or more warm air outlets normally are installed in the crawl space so that a controlled volume of heated air discharges directly into the crawl space.

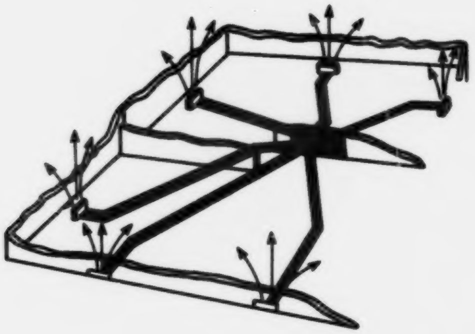

Figure 5-25. Typical Perimeter Radial System

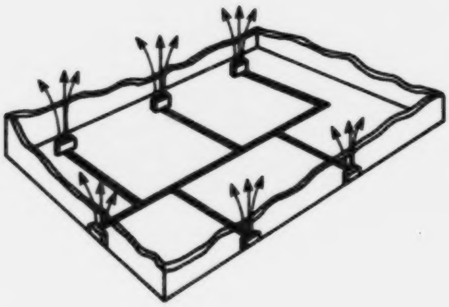

Figure 5-26. Typical Extended Plenum System

In the extended plenum system the air distribution system consists of a main trunk line, which is an extension of the furnace plenum, with individual warm air ducts branching off the main trunk line as required. As with the radial system, this system may be located in an attic or crawl space area but is normally not found embedded in concrete floors. This type of system is predominantly in homes with basements because the warm air ducts can be run between the floor joists, which allows the basement ceiling to be finished.

Return air grilles for the perimeter type heating system are usually located in a wall or ceiling in a central hall or connecting passage where they are likely to be the least conspicuous. So that odors will not be circulated throughout the home, a common return for an entire system should never be located in a kitchen or bathroom. To ensure proper operation of the distribution system, each warm air supply outlet must have an unobstructed air path back to the return air grille.

Hydronic Systems

Both hot water and steam systems are used for domestic central heating. They are usually constructed of cast iron or steel although some may be of nonferrous metal. Most domestic and hot water steam boilers are low pressure, meaning that the operating pressure does not exceed 15 psi for steam or 30 psi for water.

Hot Water Heating Systems. Two kinds of hot water heating systems are in use: forced hot water and gravity. Forced hot water systems (Fig. 5-27) have a pump that circulates the water through pipes to radiators throughout the house. Because of the excellent heat absorption capability of hot water, the required boilers are very compact. Rare now but found in some older installations, gravity systems rely on the different density of cool and hot water to circulate the water. These systems have no pump to be serviced but required large circulating pipes, large radiators and a large amount of water. Because of this mass that must be heated, these systems have high thermal inertia; that is, they are slow in warming a house when outdoor temperatures drop rapidly.

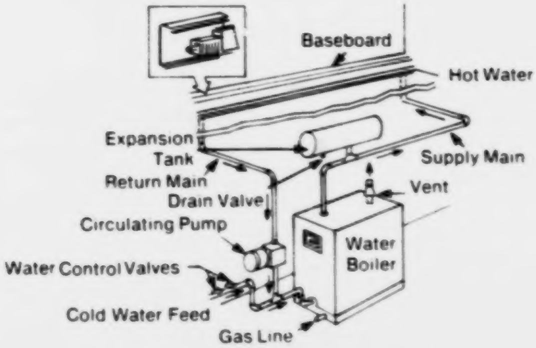

Figure 5-27. Forced Circulation Hot Water Hydronic Heating System

A typical domestic hot water boiler is shown in Fig. 5-28. The burner arrangement and combustion chamber is similar to air-heating furnaces and a boiler may have single or multiple burners. The burner controls and operating thermostat are also similar to those found on air-heating furnaces. In addition to these controls, the boilers have a high limit water temperature control that shuts off the gas supply if the water temperature exceeds a safe limit. A circulator control is also supplied to actuate the circulating pump when the water temperature in the boiler rises and then to turn it off when the water cools. These controls may be compared to the face and limit switches on forced-air furnaces. This control arrangement varies, however, since some boilers fire only when the room thermostat calls for heat, but in others water is maintained at a constant temperature and the room thermostat controls the circulator pump.

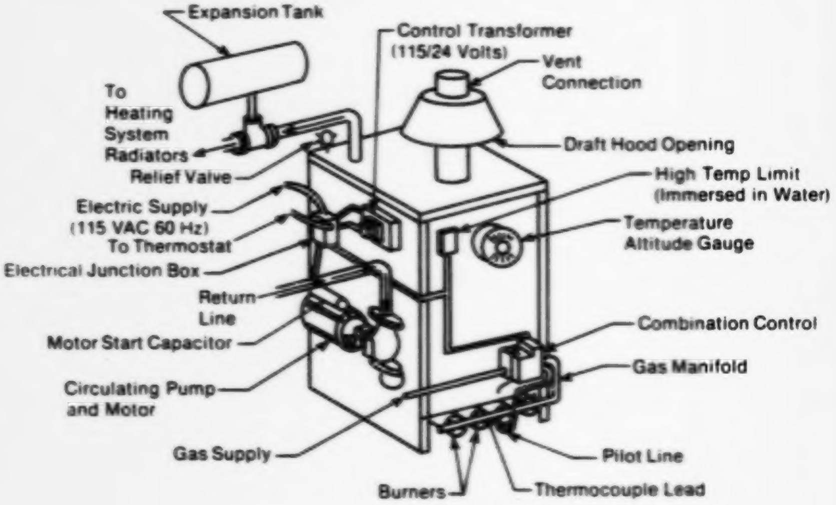
Expansion Tank
Control Transformer (115/24 Volts)
Vent Connection
To Heating System Radiators
Draft Hood Opening
Relief Valve
High Temp Limit (Immersed in Water)
Electric Supply (115 VAC 60 Hz)
To Thermostat
Temperature Altitude Gauge
Electrical Junction Box
Return Line
Combination Control
Motor Start Capacitor
Gas Manifold
Circulating Pump and Motor
Gas Supply
Pilot Line
Burners
Thermocouple Lead

Figure 5-28. Typical Hot Water Boiler

In addition to the controls described, hot water boilers have other components that should be noted. The heating system is equipped with an air-filled expansion tank placed somewhere above the boiler in the system. Since water expands when it is heated and contracts when it is cooled, this tank is necessary to accommodate these changes in volume of the water. Boilers have gauges to indicate the temperature and pressure of the water in the system. The boiler must have a pressure relief valve to guard against overpressure and a drain cock for draining the water.

Hot Water Distribution Systems. The most common type of hot water distribution system found today is the forced "zoned" series system (Fig. 5-29).

In the zoned system, the house is divided into zones to be heated. Each zone is then controlled by its own thermostat and each area is heated independently of the other zones. Typical zones may be divided into sleeping areas, areas of high activity such as the family room and living room, and areas of low activity such as the basement. The radiators in each zone are connected in series so that radiators at the beginning of the zone are normally warmer than radiators located at the end of the zone. The zone thermostat causes this zone valve to open, which, in turn, causes the pump to operate and the burner in the boiler to fire. The advantages of a forced zone system are:

- Minimum size water piping can be used.
- Different areas of the home may be heated to different temperature levels.

- Because the water flow is forced through the system with a pump, radiators may be located below the level of the boiler.

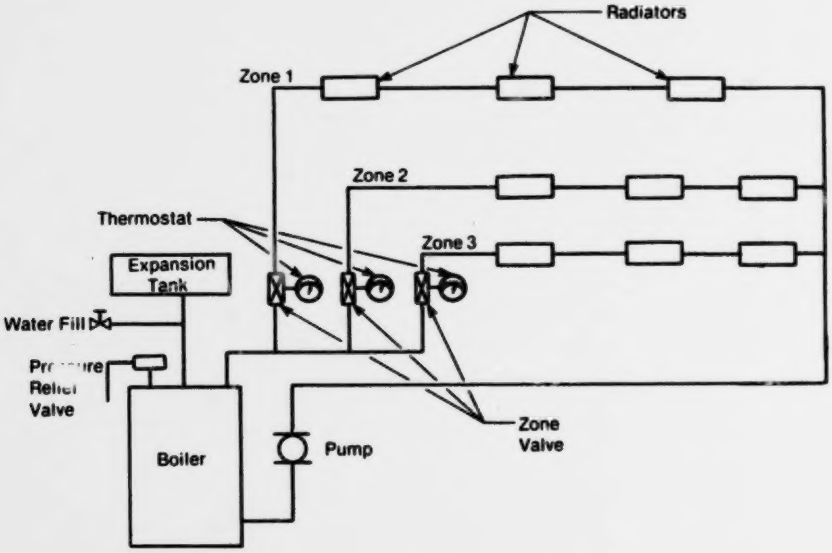
Radiators
Zone 1
Zone 2
Thermostat
Zone 3
Expansion Tank
Water Fill
Pressure Relief Valve
Boiler
Pump
Zone Valve

Figure 5-29. Typical Zoned Series System

The main disadvantage of a series systems is that because the radiators located at the end of a series are naturally cooler than those located at the beginning of the series loop, it is harder to maintain uniform temperatures within a zone unless the zone is kept relatively small.

Conversion Burners. Many coal- and oil-fired boilers and furnaces have been converted to use gas as fuel. The conversion burners are furnished as complete burner and control assemblies (Fig. 5-30). They may be equipped with atmospheric drilled or slotted multiport or single port burners. Some units have power burners. Sizes range from 40,000 to 400,000 Btu/hr input capacity. When installations are made they must be in strict accordance with manufacturer's instructions and local building codes.

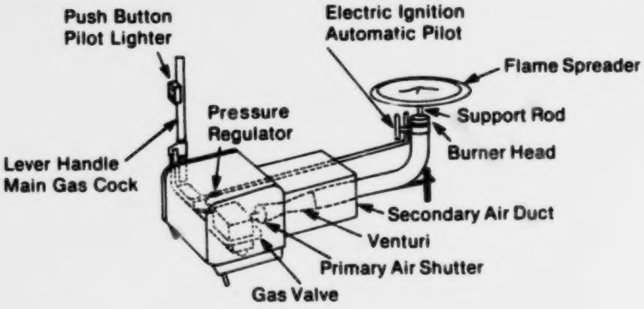
Push Button Pilot Lighter
Electric Ignition Automatic Pilot
Flame Spreader
Pressure Regulator
Support Rod
Burner Head
Lever Handle Main Gas Cock
Secondary Air Duct
Venturi
Primary Air Shutter
Gas Valve

Figure 5-30. Gas Conversion Burner

5.12 OIL-BURNING EQUIPMENT

Equipment that uses oil burners to combust the fuel have much in common with equipment that uses natural gas or LP gas burners. The main difference is in the burner itself, with slight differences found in the temperature control systems and venting system. The heat exchanger and external heat distribution system are normally identical for oil-burning equipment and gas-fired equipment.

Oil burners may be used in room heaters and furnaces and boilers for space heating oil burners in the 0.5 gal/hr to 1.0 gal/hr size range may also be used for domestic hot water heaters. Domestic oil burners are ordinarily used in the range of 0.5 gal/hr (70,000 Btu/hr) to 3.5 gal/hr (490,000 Btu/hr) fuel consumption rate. The type of fuel used is generally No. 2 fuel oil, although burners in the domestic range can also operate on No. 1 fuel oil. The vast majority of domestic oil burner production is of the high-pressure atomizing gun burner type. Substantial numbers of other types of oil burners are still in operation but only a few of these other types are currently in production.

For a complete discussion of oil burners, oil storage, and oil burner controls refer to the domestic water heating systems manual.

5.13 ELECTRIC HEATING SYSTEMS

5.13.1 Applications

Electric heating equipment may be used in decentralized or centralized systems. Electric space heating is often used where minimum initial cost is the dominating factor, or when fossil fuels (gas, oil) are not feasible.

5.13.2 Uses

In decentralized systems, electric heating equipment may be used as:

- Floor drop-in heaters
- Wall insert and surface mounted heaters
- Baseboard convectors and heaters
- Hydronic baseboard convectors with immersion elements
- Radiant wall or panel type heaters

In centralized systems, electric heating equipment may be used as:

- Furnaces for forced warm air systems
- Boilers for hydronic systems
- Heat Pumps

5.13.3 Comparison to Gas or Oil Systems

Electric space heating systems eliminate the need for gas or oil supply systems, gas manifolds and controls, special controls to ensure proper combustion and a venting system. In some applications, the resistance heating elements act as the heat exchanger so that large or massive heat exchangers are not required. However, electric space heating systems do require an electric supply system and still require a heat distribution system and temperature control system basically identical to a gas- or oil-fired central heating system.

5.13.4 Central Warm Air Systems

Using the same type distribution system as was previously discussed, warm air heating systems may be operated using an electric furnace. Electric furnaces, consisting of resistance heating coils and a blower housed in an insulated cabinet, are available in sizes ranging from 5 kW (about 17,000 Btu/hr) to 60 kW (about 200,000 Btu/hr) for use with residential ducted warm air systems. These furnaces are generally smaller and more compact than gas- or oil-fired units because the heating coils act as the heat exchanger, thus eliminating the space requirements for a conventional heat exchanger. Electric warm air furnaces still require a remotely located room thermostat, a fan switch to operate the blower, and high limit controls to prevent the unit from overheating in case of malfunction.

5.13.5 Central Hot Water Systems

Conventional hot water heating systems may be operated using an electric hot water boiler containing immersed heating elements instead of a gas or oil burner system. Such boilers are extremely compact and some may be designed for wall mounting. However, electric hot water boilers still require all of the standard components and controls associated with hot water systems, such as:

- Room thermostat
- High water temperature limits
- Pump relays
- Circulating pump
- Expansion tank
- Water pressure relief valve

5.13.6 Steam Systems

Although electric boilers are sometimes used in commercial and industrial applications to generate steam, electric steam generators are not normally found in residential applications.

5.13.7 Heat Pumps

A heat pump is simply an electrically operated compressor with two heat exchangers. One heat exchanger, or coil, is located on the low-pressure side of the compressor (normally outside the home), and the other heat exchanger, or coil, is located on the high pressure side of the compressor (normally inside the home). By blowing air over the heat exchanger located outdoors, heat is extracted from this outside air. This heat is then moved, or pumped, indoors to the second heat exchanger where the heat is reclaimed by blowing air across the second heat exchanger and then circulating this warm air to the various locations within the home where it is required.

There are four basic heat pump types as follows:

- Air-to-Air—as shown in Fig. 5-31, the outdoor coil extracts heat from the outside air and pumps it to a warm air distribution system inside the home.
- Earth-to-Air—the earth is used as a heat source with the outdoor coil buried in the earth. Heat is then pumped to a warm air distribution system as in the air-to-air systems.
- Water-to-Air—the outdoor coil is located in a water well and uses the water as a heat source. Heat is then pumped to a warm air distribution system as in the air-to-air systems.

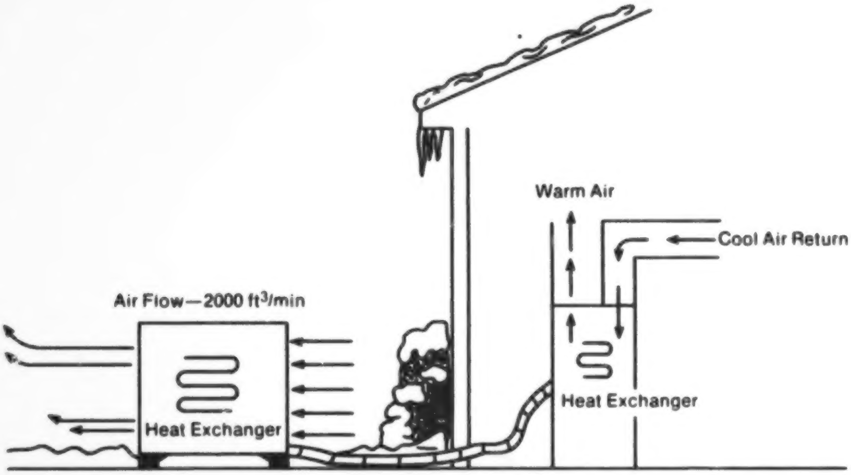

Figure 5-31. Winter Cycle of Air-to-Air Heat Pump

Other heat pump systems pump heat to an inside hot water distribution system so that it is possible to have air-to-water, earth-to-water and water-to-water systems as well.

Because heat pumps extract heat from some external sources (outdoor air, earth, water) and pump this heat inside to be used by the heat distribution system, the heat output of a heat pump is normally greater than its equivalent electrical input. For example, a typical heat pump on a normal winter day may be capable of pumping about 20,000 Btu/hr of heat into the home and only require about 10,000 Btu/hr (2.9 kWh) of electrical energy input. This ratio is referred to as the coefficient of operation performance, or COP.

One limiting feature, or drawback, of the air-to-air heat pump is that its heat output, or COP, decreases as the outdoor temperature drops or as the temperature of its heat source drops. For this reason, electric resistance duct heaters are normally used for supplemental heating during extremely cold outdoor periods. During these cold periods, the electric duct heaters are automatically energized, or turned on, to ensure adequate heat output. A limiting feature of the air-to-air heat pump is that some type of defrost cycle is required to remove any ice build-up from the outside coil and prevent it from freezing.

One advantage of heat pumps in general is that the cycle of operation may be reversed in the summer months and used to cool the home as shown in Fig. 5-32. In this mode of operation, heat is extracted from the indoor air by the indoor heat exchanger and pumped outdoors where it is disposed of by the outdoor heat exchanger.

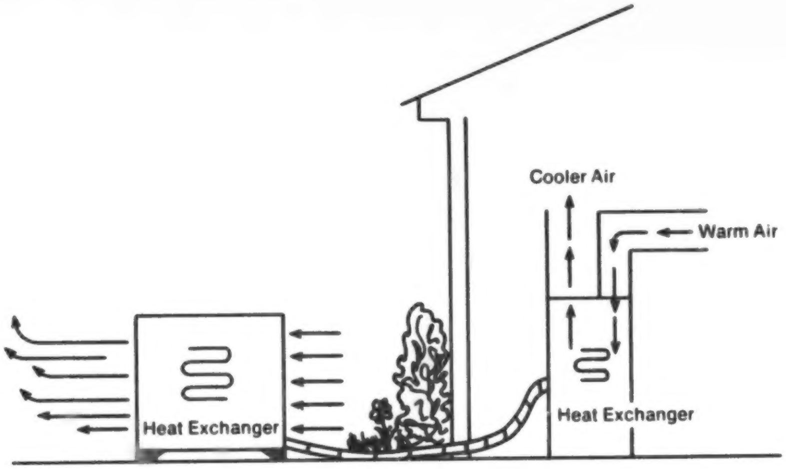

Figure 5-32. Summer Cycle of Air-to-Air Heat Pump

Heat pumps require a central heat distribution system as do central gas- or oil-fired central heating systems. In addition, heat pumps also have the following components to ensure their proper operation:

- Defrost heaters and controls
- Duct heaters (in the case of air-to-air heat pumps) and controls for supplemental heating
- Cycle changeover valves and controls

Heat pumps are adaptable to solar applications and research is presently being conducted in the use of solar energy as a heat source. Research is also being conducted by various gas equipment manufacturers to develop a gas-fired heat pump.

5.14 MAINTENANCE

For any heating system to operate safely at optimum efficiency and provide the degree of human comfort that was intended, three basic conditions must be met:

- The system must be properly designed and sized correctly for the application.
- The system must be properly installed and adjusted for the application.
- Periodic basic maintenance and servicing must be performed on the system.

If any one of the above steps is not met, poor heating system performance can be expected and, at the very worst, serious safety problems can result.

5.14.1 General

The heart of any heating system is the thermostat. It must be located in an area of the home that does not receive artificial heat, e.g., above a lamp or TV, and in an area that reflects the actual temperature in the home. Normally, outside walls, kitchen walls opposite stoves, corner locations, areas close to warm air registers and walls in direct sunlight are poor locations. The thermostat "heat anticipator" should also be properly adjusted to yield the correct cycling rate.

Warm air registers, radiators, convectors, and baseboard units should be kept clean and free of obstructions. Items of furniture and drapes should not be located so as to block air movement.

5.14.2 Gas-Burning Equipment

All fuel-burning equipment, regardless of the type fuel used, requires a sufficient amount of air to be used in the combustion process. Normally, an adequate supply of combustion air is obtained from the home through infiltration. However, if the home is of tight construction or if the heating unit is isolated from a normal path of air, then provisions must be made to supply the equipment with an adequate supply of combustion air. Signs inside the home that may indicate that additional combustion air is required are:

- Excessive moisture
- Unexplained odors
- Excessive temperatures around the heating equipment
- Chronic pilot light outages
- Unexplained headaches, drowsiness, etc.
- Products of combustion issuing from the draft hood relief opening

Most of these signs could also indicate problems in the venting system such as a blocked vent passage or undersized venting system.

The presence of these signs does not necessarily indicate a lack of combustion air. For example, chronic pilot light outages can also indicate a hole or crack in the heat exchanger. And, periodic odors may also be noticed if the hole or crack is located in the top of the heat exchanger.

If any of these problems are suspected, a qualified serviceman should be contacted immediately and the problem corrected.

Periodic maintenance of gas-fired equipment may include:

- Cleaning burners and heat exchanger surfaces
- Cleaning pilot burners and pilot gas lines
- Adjusting primary air for optimum combustion
- Checking fuel input
- Testing and adjusting combustion controls such as the gas pressure regulator
- Checking all safety controls

5.14.3 Oil Burning Equipment

In addition to the items listed under gas burning equipment, the following items in oil burning equipment should be checked for and repaired or replaced as necessary:

- Dirty or clogged oil filters
- Leaky oil lines
- Plugged vent line on oil tank
- Faulty oil pumps
- Dirty air fan
- Soot build up
- Partially plugged burner nozzle
- Operation of the barometric draft regulator
- Signs of excessive nozzle temperature
- Faulty oil pressure regulator
- Water or excessive condensation in the oil tank

5.14.4 Electric Heating Equipment

Electric duct heaters and resistance heating elements should be inspected annually and cleaned as necessary. Heat pumps, because they normally operate over long periods of time (both summer and winter), should be given special considerations. To maintain performance and reliability of a heat pump system, it is important that the refrigerant level be checked and adjusted periodically. The outdoor heat exchanger (coil) should be kept clean from tree leaves, grass, etc., and should be sprayed and cleaned at least once a year. The inside heat exchanger (coil) should be inspected at the beginning of each heating season and cleaned if necessary. Periodic maintenance of a heat pump system should also include:

- Lubrication of all motors
- Cleaning of the fan blades
- Checking all operating controls
- Checking all safety controls

5.14.5 Air Systems

Air filters should be inspected at least once a month during the heating season. Dirty filters will greatly restrict air flow, resulting in overheating of the heating plant, high fuel costs, and poor heating. If filters are of the throw-away type, new filters should be installed at the beginning and middle of the heating season and more often if inspection indicates necessity. When the furnace is used with a cooling system, new filters should also be installed at the start of the cooling season. If filters are of the cleanable type, they should be inspected and cleaned every month.

Blowers and motors should be inspected at least once each heating season and cleaned if necessary. If the bearings in blowers and motors are not sealed, they should be oiled at least once each heating season with SAE 20 oil or the oil specified on the blower or motor nameplate. Do not over-oil. Blower belts should be adjusted so that there is 2 to 3 in. of up and down slack in the loose side of the belt. Pulleys must be aligned.

Blower speed should be adjusted so that the temperature rise across the heating unit is as specified on the furnace nameplate. All air dampers should be adjusted so that the system is correctly balanced.

Fan on settings should be set as low as possible without causing discomfort, normally about 5° to 10° above the normal room temperature. The fan-off setting should be set 5° to 10° above the fan-on point.

Warm air registers and return air grilles must not be restricted or covered by rugs, draperies or furniture. When warm air ducts pass through unheated areas, they should be insulated. All air leaks in the duct system should be sealed air tight.

5.14.6 Hydronic Systems

All pumps and pump motors should be oiled at least once each heating season with SAE 20 oil. Do not over-oil. Motors on zone valves should be inspected yearly and lubricated only if specified by the manufacturer.

When water piping is located in unheated areas, it should be insulated. All water leaks should be repaired as soon as they are found. If fresh water is added to the boiler after repairs are made, it is advisable to operate the boiler or at least to raise the water temperature to the boiling point in order to permit escape of oxygen and other dissolved gasses that would be corrosive if the boiler were not put in operation immediately. All excess air should be purged from high points in the system. Do not purge air charge from the expansion tank.

All controls should be inspected at the beginning of the heating season to ensure their operation and calibration. Pressure and temperature gauges should be kept in operating order. The water pressure reducing valve and check valve should be checked at the beginning of each heating season. The pressure relief valve should be tested to ensure that it is capable of opening. The outlet connection of the relief valve must not be restricted.

5.14.7 Obsolete Equipment

Sometimes maintenance does not solve everything. Problems frequently may be caused by poor system design, faulty installation,or worn out equipment. Normally, these types of problems are well beyond the skills of the homeowner to correct. Major repairs or replacement of equipment should only be performed by qualified servicemen and in strict accordance with all national and local safety codes.

5.15 SYSTEM DEGRADATION

As was pointed out under the maintenance section, a heating system that is poorly maintained will slowly degrade with a resulting decrease in its operating efficiency and potential for serious safety problems. However, even if proper maintenance is performed on the heating system, some components, such as the heat exchanger, will naturally degrade over a long period of time.

5.15.1 Gas-Burning Equipment

Perhaps the biggest enemy of gas-fired equipment is corrosion. Because fossil fuels (natural gas, oil, propane) contain hydrogen, one of the by-products of the combustion process is water vapor. If the temperature of this water vapor is allowed to drop below its dew point before it is exhausted to the outside atmosphere, small water droplets will form (condense) on the walls of the venting system and possibly on the walls of the heat exchanger. This results in a corrosive action on the vent material causing slow deterioration of the vent. Signs that this process is occurring are small irregular holes in the vent and, if severe enough, a white powdery substance present at the joints of the vent pipe. Corrosion of the heat exchanger results in rust and rust scales in the draft head and burner area.

Factors that determine the natural corrosion rate for a heat exchanger are: material, design, environment, and maintenance. Normally any heat exchanger older than ten years should be suspected.

The heat exchanger of gas-burning equipment will naturally go through a condensating cycle, or corrosion cycle,each time the unit operates. At the beginning of each burner-on cycle, the walls of the heat exchanger are cool (below the dew point of the combustion gases) so that until the heat exchanger warms, any water vapor that comes in contact with the exchanger walls will condense on the exchanger wall and has the potential of causing corrosion. Over a long period of time, sufficient corrosion will take place and cause holes or cracks to appear in the heat exchanger. Once this has occurred the equipment must be replaced to ensure the safety of the building occupants. Signs of a faulty heat exchanger include:

- Chronic pilot light outages
- Unexplained odors
- Unexplained headaches, drowsiness, etc.

5.15.2. Oil Burning Equipment

In addition to corrosion, soot buildup is a special concern with oil-fired equipment. Soot buildup usually results from poorly adjusted oil burner controls and air adjustments. If this is the case, excessive amounts of soot can accumulate inside the furnace and substantially plug up the flue passages. This accumulation causes the oil burner to be further out of adjustment, which creates even more soot. The accumulation of soot on the flue passages also acts as insulation and decreases the overall operating efficiency of the heating equipment. Other good indications that the oil burner is out of adjustment are:

- Burner flame pulsates
- Burner flame appears stringy and dirty
- Ignition points show carbon build-up
- Oil nozzle plugs frequently
- Burner shuts down frequently on limit controls
- Burner recycles frequently
- Heater exhibits higher than normal oil consumption.

5.15.3 Electric Heating Equipment

In much the same fashion as an electric range element or electric oven element, electric duct heaters and resistance type heating elements are most apt to fail from burn-out. To eliminate electrical shorts or broken insulators, extreme caution should be observed when servicing or cleaning duct heaters or resistance heating elements.

Compressors on heat pumps typically lose efficiency with time unless properly maintained. A good indication of a failing compressor is hard starting and high current draws (electrical consumption). Possibly the most common problem with heat pumps is faulty controls that cause continuous operation of the supplemental heating coils during mild weather. A very good indication of this is abnormal electrical consumption.

5.15.4 Air Distribution Subsystems

The efficiency of an air distribution subsystem, if properly installed and maintained, should not decrease with age and the subsystem will probably last longer than the building in which it is installed.

5.15.5. Hydronic Distribution Subsystems

The biggest enemy of a hydronic distribution subsystem is water leaks, no matter how small. If a leak does exist in the system, new water is brought in to replace the water that has leaked out. The new water contains free oxygen, which accelerates internal corrosion and minerals that cause scaling and could cause blockages in the water piping. Besides an obvious leak, good indications that a leak exist are:

- Frequent air logging or water logging of the expansion tank
- Water-fall noise in the piping
- Frequent air locks that prevent water flow to one or more radiators
- Water pressure relief valve operation
- Reduced operating efficiency of the boiler

The most common points of failure with a hydronic system are zone valves and pumps. Both of these components present possible areas of water leakage and should be periodically inspected and serviced. Water leaks should be repaired as soon as they are found, otherwise permanent damage could result requiring replacement of parts of the distribution subsystem.

5.16 GLOSSARY

AIR SHUTTER - An adjustable device on the primary air openings of a gas burner used to control the amount of primary combustion air introduced into the burner.

ANODE ROD - A metal rod, usually magnesium, placed in a water heater tank to protect the tank from corrosion.

APPLIANCE FLUE - See Flue.

AUTOMATIC CONTROL VALVE - An automatic or semiautomatic device consisting of a valve and an operator. The valve controls the gas supply to the burner(s) during operation of an appliance.

AUTOMATIC PILOT - A gas pilot that lights the gas at the main burner(s) each time the appliance operates and shuts off gas supply to the burner(s) in the event of pilot flame failure.

AUTOMATIC PILOT DEVICE - A device incorporated in a gas pilot assembly that automatically shuts off the gas supply to the appliance burner(s) if the source of ignition fails.

BAFFLE - An object placed in an appliance to change the direction of or retard the flow of air, air/gas mixtures, or flue gases.

BAROMETRIC DRAFT CONTROL - A device attached to a flue outlet on some appliances without draft hoods that has a counterweighted baffle to allow dilution air to mix with the combustion products. It is used to prevent excessive draft on an appliance.

BRITISH THERMAL UNIT (Btu) - The quantity of heat required to raise the temperature of one pound of fresh water one degree Fahrenheit.

BUNSEN BURNER - A gas burner in which combustion air is injected into the burner by the gas jet emerging from the gas orifice, and this air is premixed with the gas supply within the burner body before the gas burns on the burner port.

BURNER - A device for final conveyance of gas, or a mixture of gas and air, to the combustion zone.

- Injection Burner - A burner employing the energy of a jet of gas to inject air for combustion into the burner and mix it with gas. In an Atmospheric Injection Burner, the air is injected into the burner by a jet of gas supplied to the burner at atmospheric pressure.
- Power Burner - (See also Forced Draft Burner, Induced Draft Burner, Premixing Burner, and Pressure Burner). A burner in which either gas or air or both are supplied at pressures exceeding the line pressure for gas and atmospheric pressure for air.
- Yellow-Flame Burner - A burner in which secondary air only is depended on for the combustion of the gas.

BURNER HEAD - That portion of a burner beyond the outlet of the mixer tube that contains the burner ports.

BURN-OUT - The separation of parts of a heating element as a result of burning through.

COMBUSTION - Rapid oxidation of fuel gases accompanied by the production of heat, or of heat and light. Complete combustion of a fuel is possible only in the presence of an adequate supply of oxygen.

COMBUSTION AIR - Air supplied in an appliance specifically for the combustion of a fuel gas.

COMBUSTION CHAMBER - That portion of an appliance where combustion normally occurs.

COMBUSTION PRODUCTS - Constituents resulting from the combustion of a fuel gas with the oxygen in the air, including the inerts, but excluding excess air.

CONDUCTION - Transfer of heat from one fluid or solid to another by means of actual contact between them.

CONVECTION - Transfer of heat by movement of a fluid containing the heat.

CONTROL - The methods and means of governing the operation of an appliance.

- Combination Control - Two or more control functions built into the same control or assembly.
- Fan and Limit Control - A combination control used on forced warm air furnaces that controls air fan operation and limits circulating air temperature.
- Operating Control - A control participating in the normal appliance operation or cycling of appliance operation.
- Safety Control - A control usually passive during normal operation of an appliance, and functioning to shut down operation when a hazardous condition is approached.

DIAPHRAGM VALVE - A control valve in which the main actuating means is the gas pressure on a flexible diaphragm.

DILUTION AIR - Air which enters a draft hood and mixes with flue gasses.

DIRECT HEATING APPLIANCES - Direct heating appliances are room heaters, recessed heaters, furnaces, decorative and similar appliances such as gas-burning fireplaces, located in occupied areas.

DIRECT SPARK IGNITION SYSTEM - An ignition system in which gas is ignited directly by a continuous spark formed between two high-voltage electrodes. No intermediate pilot flame is used.

DIRECT VENT APPLIANCES - Appliances constructed and installed so all air for combustion is derived from the outside atmosphere and all flue gasses are discharged to the outside atmosphere.

DRAFT HOOD (DRAFT DIVERTER) - A device built into an appliance or made a part of the flue or vent connector from an appliance designed to (1) provide for the ready escape of the flue gases in the event of no draft, back draft, or stoppage beyond the draft hood; (2) prevent a back draft from entering the appliance; and (3) neutralize the effect of stack action of the chimney or gas vent upon operation of the appliance.

DRAFT REGULATOR - A device that maintains a desired draft in the appliance by automatically reducing the draft to the desired value.

ENERGY CUTOFF - A thermostatic element placed in the control circuit of a water heater that shuts off energy supply in case of excessively high water temperature.

EXCESS AIR - Air that passes through the combustion chamber and the appliance flues in excess of that theoretically required for complete combustion.

FAN AND LIMIT CONTROL - See Control.

FLAME SWITCH - A thermostatic control element responsive to high temperature and thereby used to sense presence of flame.

FLUE - The general term for the passageways in an appliance and vents through which combustion products pass to the outside atmosphere.

- Appliance Flue - The flue passageways within an appliance.
- Chimney Flue - The vertical conduit for conveying combustion products delivered to it by a vent connector to the outside atmosphere.

FLUE GASSES FLUE PRODUCTS - Products of combustion and excess air in appliance flues or heat exchangers before the draft hood.

FLUE OUTLET - The opening provided in an appliance for the escape of flue gasses.

FORCED DRAFT BURNER - A burner in which combustion air is supplied by a fan or blower.

FUEL - Any substance used for combustion.

FUEL GAS - Any substance in a gaseous form when used for combustion.

HEAT ANTICIPATOR - A small resistance heater in a wall thermostat that, by heating the thermostat enclosure, causes the thermostat to cycle to off before the set room temperature is reached.

HEAT EXCHANGER - Any device for transferring heat from one fluid to another.

HEATING VALUE - The number of British thermal units produced by the complete combustion at constant pressure of one cubic foot of gas. Total heating value includes heat obtained from cooling the products to the initial temperature of the gas and air and condensing the water vapor formed during combustion.

HYDROCARBON - Any of a number of compounds composed of carbon and hydrogen.

HYDRONIC HEATING SYSTEM - A central heating system that uses heated water or steam carried through pipes to supply heat throughout the structure.

HUMIDISTAT - A device to sense and control the amount of moisture (relative humidity) in circulating air.

IGNITION - The act of starting combustion.

IMPINGEMENT TARGET BURNER - A burner consisting simply of a gas orifice and a target, with the gas jet from the orifice entraining combustion air in the open and the mixture striking and burning on the target surface. No usual burner body is used.

INJECTION - Drawing primary air into a gas burner by means of a flow of fuel gas.

INPUT RATE - The quantity of heat or fuel supplied to an appliance, expressed in volume or heat units per unit time, such as cubic feet per hour of Btu per hour.

INPUT RATING - The gas-burning capacity of an appliance in Btu per hour as specified by the manufacturer. Appliance input ratings are based on sea level operation and need not be changed from operation up to 2000 ft elevation. For operation at elevations above 2000 ft, input ratings should be reduced at the rate of 4% for each 1000 feet above sea level.

INSTANTANEOUS WATER HEATER - A water heater that essentially only heats water as it is used.

LIQUEFIED PETROLEUM GASSES- Liquefied Petroleum Gases, LPG and LP Gas mean and include any fuel gas composed predominantly of any of the following hydrocarbons or mixtures of them: propane, propylene, normal butane or isobutane, and butylenes.

LISTED - Equipment or materials included in a list published by a nationally recognized testing laboratory that maintains periodic inspection of production of listed equipment or materials and whose listing states either that the equipment or material meets nationally recognized standards or has been tested and found suitable for use in a specific manner.

LNG - Liquefied natural gas. Natural gas that has been cooled until it becomes a liquid.

METHANE - A hydrocarbon gas with the formula CH_4, the principal component of natural gasses.

MIXER - That portion of a burner where air and gas are mixed before delivery to the burner ports.

1. Mixer Face - The air inlet end of the mixer head.
2. Mixer Head - That portion of an injection type burner, usually enlarged, into which primary air flows to mix with the gas stream.
3. Mixer Throat (Venturi throat) - That portion of the mixture that has the smallest cross-sectional area and that lies between the mixer head and the mixer tube.
4. Mixer Tube - That portion of the mixer that lies between the throat and the burner head.

MODULATING CONTROL - A control capable of varying the supply of gas to a burner and thereby heat input to the appliance in a continuous fashion over its range of control.

NAMEPLATE - A plate affixed to an appliance that gives such information as manufacturer's name, appliance input rate, model number, serial number, certification, etc.

NATURAL GAS - Any gas found in the earth, usually methane, as opposed to manufactured gasses.

ORIFICE - An opening in an orifice cap (hood), orifice spud, or other device through which gas is discharged and whereby the flow of gas is limited and/or controlled.

ORIFICE SPUD - A removable plug or cap containing an orifice that permits adjustment of the gas flow either by substitution with a spud having different sized orifices (fixed orifice) or by motion of an adjustable needle into or out of the orifice (adjustable orifice).

PILOT - A small flame used to ignite the gas at the main burner.

POWER BURNER - See Burner.

PREMIXING BURNER - A burner in which all, or nearly all, combustion air is mixed with the gas as primary air.

PRESSURE BURNER - A burner in which an air and gas mixture under pressure is supplied, usually at 0.5 to 14 in. water column.

PRESSURE REGULATOR - A device for controlling and maintaining a uniform outlet gas pressure.

PRESSURE-TEMPERATURE RELIEF VALVE - A device applied to water heaters that will open to pass water or steam, if excessive pressure or temperature occurs in the water heater tank.

PRIMARY AIR - The air introduced into a burner that mixes with the gas before it reaches the port or ports.

PRIMARY AIR INLET - The opening or openings through which primary air is admitted into a burner.

PROPANE - A hydrocarbon gas heavier than methane but lighter than butane. It is used as a fuel gas alone, mixed with air, or as a major constituent of liquefied petroleum gasses.

RADIATION - Heat transfer between a hot object and a cooler one without heating of the atmosphere between.

REGULATOR - See Pressure Regulator.

RELIEF OPENING - The opening in a draft hood to permit ready escape to the atmosphere of flue products from the draft hood in the event of no draft, back draft, or stoppage beyond the draft hood, and to permit inspiration of air into the draft hood in the event of a strong chimney updraft.

SAFE LIGHTING VALVE - A manual gas valve that permits gas flow to the pilot burner but not the main burner for safety when lighting the pilot.

SAFETY CONTROL - See Control.

SAFETY SHUTOFF DEVICE - A device that shuts off the gas supply to the main burner(s), if the source of ignition fails.

SAIL SWITCH - An electrical switch actuated by force of fluid flow, acting on a vane or sail inserted in the flowing stream.

SECONDARY AIR - Combustion air externally supplied to a burner flame at the point of combustion.

SELF-GENERATING SYSTEM - A control system that, by conversion of thermal energy into electrical energy, operates with no electrical power supplied from an ouside source.

SENSOR - The primary component of a control or measuring system that senses the condition of the controlled variable.

SINGLE-PORT BURNER - A burner in which the entire air-gas mixture issues from a single port.

SOFT FLAME - A flame partially deprived of primary air such that the combustion zone is extended and inner cone is ill-defined.

SOLENOID - A coil of wire that creates a magnetic field when electricity flows through it and, hence, tends to pull a movable iron core placed within the coil.

SOLENOID VALVE - A valve actuated by an electric solenoid.

STANDBY LOSS - Heat energy required to maintain stored water at an elevated temperature.

STORAGE WATER HEATER - A water heater that stores the water for use in the same vessel in which it is heated.

SYNTHETIC NATURAL GAS (SNG) - Gas manufactured to duplicate natural gas.

TEMPERATURE AND PRESSURE RELIEF VALVE - See Pressure-Temperature Relief Valve.

THERMOCOUPLE - A device consisting of two wires or strips of dissimilar materials joined together at one end (hot junction). When this hot junction is heated, the thermocouple produces a DC voltage across the other two ends (cold junction).

THERMOPILE - a number of thermocouples connected in series to produce a higher voltage than a single thermocouple.

THERMOSTAT - A switching device that is temperature operated to control operation of an appliance.

5.17 REVIEW QUESTIONS

Domestic Water Heating Systems

1. A water heater which stores water at an elevated temperature and automatically operates a heat source is called an ______________ ______________ type.

2. The gas flow to the main gas burner is controlled by the:

   a. Dip tube
   b. Gas valve
   c. Draft hood
   d. Power burner

3. The ______________ rod helps to prevent tank corrosion by corroding in preference to the steel tank.

4. Draft hood spillage is a sign of:

   a. Defective pilot
   b. Sufficient combustion air
   c. Improper gas vent operation
   d. Low water level

5. Vent systems that utilize natural "Chimney Action" to operate are called:

   a. Power vents
   b. Gravity vents
   c. Common induced draft vent
   d. None of the above

6. The flue of a water heater performs two functions: (1) it conducts the ______________ products to the vent systems, and (2) it serves as the heat ______________ of the water heater.

7. The thermostatic control is usually located to sense ______________ temperature in the lower part of the tank so it can turn on the gas supply to reheat whenever cold water is in the tank.

8. Instantaneous water heaters store an appreciable quantity of water for instant use.

   True
   False

9. The high pressure ______________ type burner supplies oil to the nozzle at pressures of 100 psi to 300 psi.

10. The electric water heater utilizes an ______________________ heating element instead of a gas or oil burner.

11. To assure long life and efficiency the tank should have some water ____________ periodically to help prevent ______________ build up in the tank bottom.

12. The draining procedure can best be accomplished by:

    a. Opening the hot water outlet valve
    b. Turning the water heater upside down
    c. Opening the valve at the bottom of the tank
    d. Opening the gas valve

13. Annual water heater maintenance should include:

    a. Removing and cleaning the ______________.
    b. Cleaning scale and rust from the ______________ tube.
    c. Checking the ______________ rod and replacing as necessary.
    d. Inspecting the ______________ systems and ______________ hood.

14. The biggest enemy of any water heater is:

    a. Water flashing to steam causing explosions
    b. Corrosion
    c. Flame rollout
    d. Excessive Pressure

15. Condensation in the vent systems is the result of water vapor in the combustion gasses being chilled below the ______________ ______________.

Residential Heating Systems

1. What is the purpose of a heating system?

2. A basic heating system includes as a minimum:

    a. Thermostat, chiller, heater and control system
    b. Heat generating unit, heat distribution system, heated area, outdoor coil
    c. Human occupant, heat generating unit, control system, heat distribution system
    d. Furnace, water heater, venting system, fuel gas piping

3. The gas pressure regulator, pilot safety valve and main gas valve are all part of what component on a gas-fired heating unit?

4. The pilot burner is located:

    a. In the blower compartment
    b. In the main flue outlet
    c. On the pilot safety valve
    d. In the main burner compartment

5. The pilot flame ______________ the thermocouple which in turn produces an ______________ signal which energizes the pilot safety valve and keeps it ______________.

6. The amount of gas delivered at the main burner can be controlled by:
   - a. The size of the orifice
   - b. The size of the heat exchanger
   - c. The size of the blower assembly
   - d. The heating valve of the gas

7. On a gas fired unit, the heat exchanger is:
   - a. Located in the duct system external to the furnace.
   - b. Located directly above the main burner or burners
   - c. Made of light sheet metal
   - d. Located on the inlet side or the blower compartment

8. What is the purpose of the venting system?

9. Controls which cause the appliances to operate for its intended use are called:
   - a. Safety controls
   - b. Operational controls
   - c. Blower off switches
   - d. Limit thermostats

10. Controls which function to prevent a hazardous operation are called:
    - a. Safety controls
    - b. Operating controls
    - c. Blower on switches
    - d. Limit thermostats

11. Operating controls should be ______________ for greatest comfort and optimum operation of the system.

12. The two different types of heating systems in use today are:
    - a. Electric and geothermal
    - b. Centralized and decentralized
    - c. Water and gas
    - d. Gas and centralized

13. The two general classifications for centralized heating systems are:
    - a. Gas and propane
    - b. Warm air and hydronic
    - c. Warm air and gravity
    - d. Gravity and forced air

14. What component automatically operates the furnace to maintain the desired temperature in the heated areas?

15. The two main types of forced warm air distribution systems are:

    a. The radial system and extended plenum system
    b. The radial and crawl space systems
    c. The branch duct and short plenum systems
    d. Gas and electric

16. What are the two main classifications of hydronic systems?

17. A steam heating system has an expansion tank.

    a. True
    b. False

18. The most common type hot water distribution system found today is the:

    a. Gravity zoned system
    b. Zoned steam with reverse returns
    c. Zoned series system
    d. Gravity steam with two zones

19 Steam heating systems normally require a circulating pump to force the flow of steam.

    a. True
    b. False

20. Electric heating systems eliminate the need for:

    a. Gas or oil supply systems
    b. Gas manifolds
    c. Combustion controls and venting systems
    d. All of the above

21. Electric warm air furnaces are generally smaller and more compact than gas or oil fired units because the heating coils act as the ____________________.

22. The COP on a heat pump means:

    a. Coefficient of operation
    b. Coefficient of performance
    c. Coefficient of operation performance
    d. Coefficient of pumping

23. Chronic pilot light outages, unexplained odors and unexplained headaches may indicate:

    a. Low fuel level in the oil tank
    b. Dirty air blower
    c. Faulty heat exchanger
    d. Plugged pilot line

24. The biggest enemy of a hydronic distribution system is:

    a. Water levels too high
    b. Water levels too low
    c. Water leaks
    d. No expansion tank air

CHAPTER 6

PASSIVE SOLAR SYSTEMS

This chapter is presently being researched and should be completed in the future. Upon its completion a copy will be sent to you.

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CHAPTER 7

WIND ENERGY DEVICES

7.1 INTRODUCTION

Installers and inspectors of wind energy devices under the RCS program are expected to have certain qualifications that are indicative of a familiarity with the standards and construction techniques concerning wind energy devices. The Federal Register. 24 September 1980, covers much of this information. Other knowledge necessary is machine specific, and an installer should be trained by the manufacturer or his representative, and have experience in all aspects of the installation of the specific wind machine including the siting, foundation, erection, electrical systems, and checkout of the machine. In addition to knowing these details about the wind machine, the inspector must be familiar with local codes governing the installation of wind machines. This knowledge is necessary to determine compliance on the part of the manufacturer and installer with the requirements placed on them when performing an installation under the RCS program.

The purpose of this chapter is not to train an installer or inspector in the details of a specific wind machine. Instead, it is intended to provide the background material that they are required to know for the RCS program. The four topics covered are:

- RCS Installation Standards
- Structural Characteristics of Wind Machines
- National Electric Code Governing Interconnection
- RCS Test Procedure

Following a discussion of these topics, in a format that has the technical language of the RCS requirements and an interpretation of them, is a glossary of terms.

7.2 RCS INSTALLATION STANDARDS

7.2.1 Siting

The Small Wind Energy Conversion Systems (SWECS) shall be installed according to the area and setback requirements of local codes governing wind energy devices. If existing local codes are not specific to the installation of a wind energy device, the SWECS shall be installed such that during operation, no part of the SWECS extends over a property line or utility easement.

In some situations, there will be no codes or ordinances dealing with the installations of a tower and wind energy device. In that case, the concerns covered by the standard are to ensure that operation of the SWECS does not infringe on other property rights or easements.

7.2.2. Manufacturer's Instructions

The manufacturer is required to provide information concerning the specific details of the installation of his wind machine. This ensures that the installer, inspector, utility, and end user all have information they need to allow proper installation and use of the machine to the manufacturer's requirements. For an example of a SWECS installation, see Fig. 7-1.

The information provided shall, at a minimum, include the following:

- A standard foundation and anchor design or specifications for normal soil conditions.
- A detailed parts list.
- Detailed instructions for the assembly, installation, checkout, operation, and maintenance of the SWECS at a typical site.
- A warning statement, placed on the first page of the documents, containing the following instructions or equivalent: "Warning: Installation of This Product Near Power Lines Is a Danger. For Your Safety, Follow the Installation Directions."
- For interconnected SWECS, information and instructions for interconnecting the SWECS to a utility company's electrical system in a manner that meets the requirements specified in the section entitled "SWECS Electrical Interface".
- Grounding and lightning procedures protection that adhere to the National Electrical Code (NEC) articles 250 (Grounding) and 280 (Lightning Arresters). Where the design features of particular SWECS require deviation from the NEC, the SWECS manufacturer shall specify grounding and lightning protection requirements and indicate where they deviate from the NEC.

As is evident from the standard, each installation will be specific to the design of the manufacturer. It is the job of the installer to perform his job as per those instructions and based upon his experience with that particular wind energy device. It is the job of the inspectors to verify installation as per manufacturer's instructions.

7.2.3 Installer's Responsibility

The installer must install the wind machine as specified by the manufacturer. If the installer needs to make a structural change, he must have approval from the manufacturer. The installation information, including changes, will be made available to the inspector as prescribed below.

The installation may deviate from the SWECS manufacturer's instructions under the following conditions:

- Where the onsite installation requires that procedures or components deviate from the SWECS manufacturer's standard written instructions or approved components list, the installer shall obtain prior written approval from the SWECS manufacturer specifying such deviations.
- Where the tower foundation and anchors require modifications from the standard design (or specifications) provided by the SWECS manufacturer, due to actual soil conditions not considered normal, the installer shall obtain from the SWECS

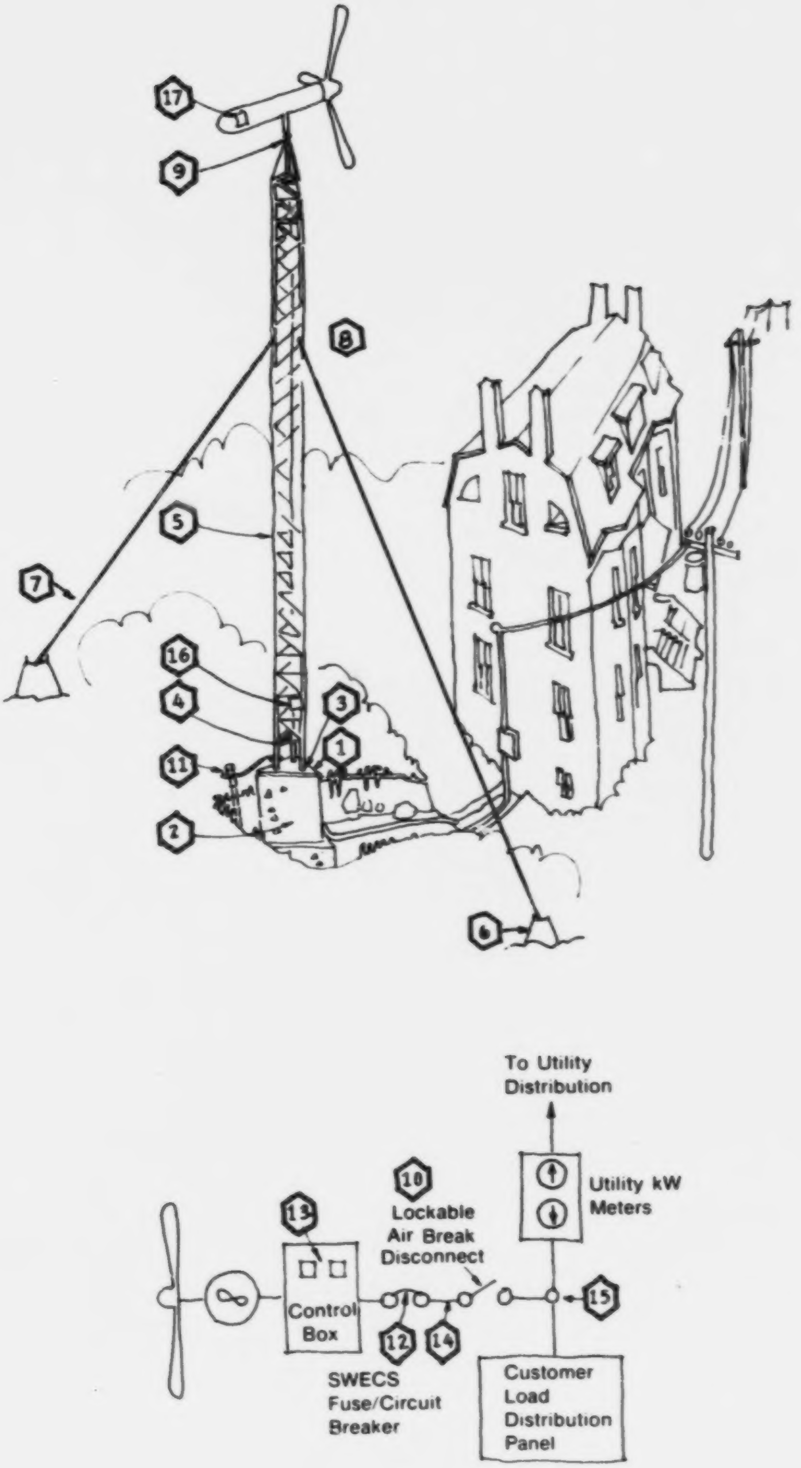
17
9
8
5
7
16
4
3
1
11
2
6
To Utility Distribution
10
Lockable Air Break Disconnect
Utility kW Meters
13
Control Box
12
14
15
SWECS Fuse/Circuit Breaker
Customer Load Distribution Panel

Figure 7-1. Wind Energy System

manufacturer, his designated representative, or a registered professional engineer, a foundation/anchor design (or specification) suitable for the characteristics at the site.

In the case of an interconnected SWECS, the installer or his designated representative shall, upon request, provide the local utility with installation procedures, and the final test report on the performance and safety of the SWECS to be installed if such SWECS data is not already on file with the utility.

The installer shall notify the state-designated inspection authority of the installation within one day of completing the installation. A copy of the SWECS manufacturer's installation instructions, together with any appropriate written approval(s) of deviation from those instructions, shall be provided to the state-designated inspection authority by the installer within four days of completion of the installation, if such SWECS data is not already on file with the utility.

7.3 STRUCTURAL CHARACTERISTICS OF WIND MACHINES

Wind energy conversion system designers have discovered that SWECS represent a system of interacting substructures that requires complex static and dynamic analyses to ensure a safe and reliable installation and operation. Installers and inspectors should be familiar with the critical structural parameters considered by the SWECS designer to ensure the total system is installed properly from a structural point of view.

These critical parameters are:

- Site soil properties
- Local building ordinances/structural design criteria specified for wind loading
- Tower foundation
- Tower
- Guy wire (if applicable)
- Guy-wire anchor (if applicable)
- Critical attachments — methods and procedures

The following provides a synopsis of the significance of the above parameters as they relate to the structural safety and reliability of an installed wind energy conversion system.

7.3.1 Site Soil Properties

Once a SWECS site is selected, the soil properties of that site should be examined by the installer in sufficient detail to ensure that the foundation design provided by the manufacturer is suitable. If the proposed site soil differs from the normal soil properties for which the tower foundation was designed, modifications need to be made to accommodate the site soil properties. These modifications must be made or approved by the SWECS manufacturer or a certified professional civil structural engineer. For tower foundation and guy-wire anchors, the soil directly under the proposed location(s) should be investigated to a depth equal to the width of the foundation/anchor. A minimum of two bore holes is required to adequately define the soil properties. These bore holes should be drilled at opposite corners of the foundation/anchor site.

7.3.2 Local Building Ordinances/Structural Design Criteria

The structural design of a SWECS is based on a specified maximum wind speed that can be related to a dynamic pressure on the surface of the SWECS rotor and structure. A suitable factor is typically applied to this design criteria to ensure adequate safety margins. The installer/inspector should verify that the local building ordinance wind velocity (or equivalent loading) criteria does not exceed the design survival wind speed for the system to be installed. If the local building ordinance criteria exceeds the specific SWECS survival wind velocity, it is recommended that installation of the SWECS not be approved for safety reasons.

7.3.3 Tower

The safety and reliability of an installed SWECS can be reasonably assured only if the tower specified by the SWECS manufacturer is used. The identified tower must be marked with the manufacturer's make, model, and height of tower. Since structural characteristics of the SWECS are critically dependent on the dynamic as well as the static characteristics of the tower, extreme care must be taken by the installer and inspector to ensure the installation of only those towers specified by the SWECS manufacturer that were verified to be safe by atmospheric testing. Although a given tower may appear to be adequate, dynamic response of the structure (at or near the normal frequency of critical elements of the structure) may cause failures in the structure not normally anticipated if judgments are made on static adequacy alone. The determination of the dynamic adequacy is not a simple calculation, and, therefore, the substitution of a tower design and/or a change in the height of a tower from that specified by the SWECS manufacturer is not recommended.

7.3.4 Tower Foundation

A SWECS foundation consists of one or more elements that provide support for the SWECS tower and guys, if guys are present. For the purpose of design, a combination of the following factors should be considered for each element:

- Overturning moment
- Vertical bearing capacity
- Uplift resistance
- Lateral bearing capacity

If the installer chooses to use a foundation specified by the SWECS manufacturer who has determined that it will provide safe and reliable operation for specified wind pressure and soil conditions, it is the responsibility of the installer to ensure that the site wind pressure and soil conditions do not exceed the manufacturer's ultimate limits. The site wind pressure and soil conditions should be determined in accordance with Uniform Building Code Sections 2311 and 2906 and/or local building codes.

Section 2906*

The allowable foundation and lateral pressures shall not exceed the values set forth in Table 29-B unless data to substantiate the use of higher values are submitted. Table 29-B may be used for design of foundations that have continuous footings having a load of less than 2000 lb/ft and isolated footings with loads of less than 50,000 lb.

Section 2311*

(a) Towers supporting SWECS shall be designed to withstand the minimum horizontal and uplift pressures set forth in Table 23-F and this section allowing for wind from any direction. The wind pressures set forth in Table 23-F are minimum values and may be adjusted by the building official for areas subjected to higher wind pressures. When the form factor, as determined by wind tunnel tests or other recognized methods, indicates vertical or horizontal loads of lesser or greater severity than those produced by the loads herein specified, the structure may be designed accordingly.

(b) Horizontal Wind Pressure. For purposes of design, the wind pressure shall be taken upon the gross area of the vertical projection of that portion of the tower or structure measured above the average level of the adjoining ground.

(c) Anchorage Requirements. Adequate anchorage of the tower to the foundation so as to resist overturning, uplift, and sliding shall be provided in all cases.

(d) Moment of Stability. The overturning moment calculated from the wind pressure shall in no case exceed two-thirds of the dead load resisting moment. The weight of earth superimposed over footings may be used to calculate the dead load resisting moment.

(e) In the case of higher wind pressure distribution, the design should meet local codes for such structures and be approved by a certified professional engineer.

In the case where a foundation design other than the SWECS manufacturer's or tower manufacturer's is used, the design should incorporate the above-mentioned codes and be approved by a certified professional engineer.

7.3.5 Guy Wire (if applicable)

This section is applicable for towers designed to be supported by guy wires and does not apply to free-standing tower designs. Towers that incorporate guy wires for structural support must have the correct gauge material strength and pretension force as specified. Not only do the guy wires provide the necessary static strength to the structure but they also significantly affect the dynamic characteristics of the tower such that if guy wire size, strength, or pretension are not as prescribed by the SWECS manufacturer, the tower structure might fail. Therefore, it is essential that the installer/inspector verify that the guy wire installed on the tower structure is as specified by the SWECS manufacturer.

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*Uniform Building Code. C 1979. International Conference of Building Officials.

Table 29-B. ALLOWABLE FOUNDATION AND LATERAL PRESSURE

Class of Materials(b)	Allowable Foundation Pressure (lb/ft^2)(c)	Lateral Bearing (lb/ft^2) Ft of Depth Below Natural Grade(d)	Lateral Sliding(a)	
			Coefficient(e)	Resistance (lb/ft^2)(f)
1. Massive Crystalline Bedrock	4000	1200	.79	
2. Sedimentary and Foliated Rock	2000	400	.35	
3. Sandy Gravel and/or Gravel (GW and GP)	2000	200	.35	
4. Sand, Silty Sand, Clayey Sand, Silty Gravel and Clayey Gravel (SW, SP, SM, SC, GM and GC)	1500	150	.25	
5. Clay, Sandy Clay, Silty Clay and Clayey Silt (CL, ML, MH and CH)	1000g	100		130

)Lateral bearing and lateral sliding resistance may be combined.

(b) For soil classifications OL, OH, and Pt (i.e., organic clays and peat), a foundation investigation shall be required.

(c) All values of allowable foundation pressure are for footings having a minimum width of 12 inches and a minimum depth of 12 inches into natural grade. Except as in Footnote (g) below, increase of 20 percent allowed for each additional foot of width and/or depth to a maximum value of three times the designated value.

(d) May be increased the amount of the designated value for each additional foot of depth to a maximum of 15 times the designated value. Isolated poles for uses such as flagpoles or signs and poles used to support buildings which are not adversely affected by a 1/2-inch motion at ground surface due to short-term lateral loads may be designed using lateral bearing values equal to two times the tabulated values.

(e) Coefficient to be multiplied by the dead load.

(f) Lateral sliding resistance value to be multiplied by the contact area. In no case shall the lateral sliding resistance exceed one-half the dead load.

(g) No increase for width is allowed.

Table 23-F. WIND PRESSURES FOR VARIOUS HEIGHT ZONES ABOVE GROUND[1]

Height Zones (in feet)	Wind-Pressure Map Areas (pounds per square foot)						
	20	25	30	35	40	45	50
Less than 30	15	20	25	25	30	35	40
30 to 49	20	25	30	35	40	45	50
50 to 99	25	30	40	45	50	55	60

[1] See Figure No. 4. Wind pressure column in the table should be selected which is headed by a value corresponding to the minimum permissible, resultant wind pressure indicated for the particular locality.

The figures given are recommended as minimum. These requirements do not provide for tornadoes.

7.3.6 Guy-Wire Anchors

This section is applicable for tower designs to be supported by guy wires and does not apply to free-standing tower designs. The design of the guy-wire anchor must meet the same basic compatibility requirement between the structural design of the anchors and the site soil properties as those requirements of the tower foundation. The same precautions must apply to guy-wire anchors as those of the tower foundation. If an incompatibility exists between the anchor design and the site soil properties, the anchor design must be modified to accommodate the actual soil properties at the site. Similarly the site-specific modification must be done only by either the SWECS manufacturer, or a certified professional civil/structural engineer. In addition to the consideration of the guy-wire anchor design, the installer/inspector must pay careful attention to the location of the specified anchor. Both the radial distances from the tower foundation and the angular placement of the anchors about the tower foundation are critical parameters. The radial distance of the anchor will significantly affect the angle of attachment of the guy wires at both the tower and anchor location. The angle at which the anchors are placed about the tower foundation could affect the load distribution between the various guy wires and again possibly adversely affect the structural integrity of the installed system. As with the tower foundation, the installer/inspector should ensure that the specified guy-wire anchor design is compatible with the site soil properties and is constructed in accordance with the SWECS manufacturer's specifications.

7.3.7 Critical Structural Attachments — Methods and Procedures

Since a SWECS is a network of interconnected dynamic subsystems each of which has a number of degrees of freedom and resultant natural frequencies, proper attachment of these components is essential to the safe operation of the SWECS. Movement between the various components caused by their dynamic response to such forcing functions as the rotation of the rotor blades and even wind pressure on the structural portion of the SWECS will tend to loosen even the most carefully secured component. Since certain attachments are critical to ensure safe operation of the SWECS, the installer/inspector should pay careful attention to the manufacturer's recommended methods and procedures for safely securing those components. Typically these are:

- Rotor-blade-to-rotor-shaft/hub assembly
- Wind turbine generator to tower
- Guy wire to tower (if applicable)
- Guy wire to anchor (if applicable)
- Tower-to-tower foundation.

In summary, the structural safety and reliable operation of SWECS is highly dependent on the seven criteria parameters identified in this section. It is essential that the installer and inspector be familiar with these parameters and ensure that proper precautions are taken as recommended by the SWECS manufacturer who has designed and verified by extensive atmospheric testing that this SWECS is safe and reliable.

7.4 SWECS ELECTRICAL INTERFACE

In the RCS program, there are numerous electrical requirements that SWECS must meet. The principal concern is for safety for personnel and electrical equipment. The human safety factor is considered in designing equipment to assure that humans can be isolated from the electrical source. The equipment safety factor is assured by compliance with accepted electrical practice as determined by the National Electrical Code and local codes that may also apply.

Interconnected SWECS must be installed to meet the following electrical requirements:

- The SWECS-to-utility electrical interconnection circuit shall incorporate a safe means to automatically and/or manually disconnect the SWECS electrically from the utility electrical system such that, in the event of a utility loss of power, an emergency, or servicing of the SWECS or the utility distribution system, personnel are protected from hazardous electrical contact. The disconnects shall not interfere with reliability of service and the normal operation of circuit breakers, fuses, and other protective devices. The disconnect shall be lockable in the open-circuit position, and access to the disconnect shall be available to the utility company at all times.
- NEC article 230 (services) shall apply, except where the local utility has specific requirements for the method of interconnecting to their electrical system and that the local utility considers adequate in lieu of NEC article 230.
- The interconnection to the utility electrical/user load shall be electrically located on the user's side of the utility revenue meter.

This section covers the requirement that any interconnection of a SWECS to a utility system or electrical system of a residence comply with the established codes in a locality, that are usually modeled after the NEC. (For background in these areas, the NEC should be consulted.)

In general, the SWECS may be designed to operate in parallel with the utility grid for an intertied system. Regardless of the type of interconnection, when the utility line is deenergized the SWECS is designed to deenergize. A lockable, visible disconnect is a required piece of equipment under the RCS program to ensure that the SWECS can be manually isolated from the utility grid.

The two major methods of accomplishing this interconnection in the current SWECS commercial market is by use of an induction generator or a line-commutated synchronous inverter. Both of these systems require the controlled voltage and frequency and lagging KVARS provided by the utility grid and consume some power in their operation. The output of these devices, to the customer, is represented as a 3 or 4 wire "intertie" which an electrical contractor hooks into the line on the customer's side of the utility billing meter. (See Section 7.7,Figure 11.)

Concerns exist as to the difficulties to be encountered by interconnected SWECS with regard to over- and under-voltage protection, over-and under-voltage protection "quality of power", harmonics, "flicker", and lightning surge protection. In practice, debilitating problems in these areas have not been realized by the owners of those SWECS now in operation. While these concerns are legitimate, additional experience will dictate where additional safety devices might be required. Electro-mechanical devices which provide a degree of protection are available to address these concerns, but no standard exists to require any or all of these devices on a SWECS installation today.

7.5 TEST PROCEDURES

There are two aspects of test procedures covered in this section: performance and instrumentation.

7.5.1 Performance

Performance in the case of SWECS is determined by the power output of the machine in a standard format that allows a comparison with other wind machines. This involves taking into account the density of the air and the variability of the wind speeds that the wind machines encounter.

The following SWECS performance characteristics shall be determined through atmospheric testing by the SWECS manufacturer or a separate testing organization designated by the SWECS manufacturer. If the SWECS manufacturer modifies the SWECS model in a way that significantly impacts the performance of the SWECS, the new model shall be tested in accordance with the requirements of the appropriate paragraph under "Test Methods" in this section.

(1) Power Output Curve. The SWECS power output shall be defined as a function of wind speed at the center of the SWECS rotor for wind speeds up to 33.6 mph or the SWECS cutout speed, if achieved during the atmospheric test. The SWECS power output curve shall be derived from discrete wind speed and corresponding SWECS power output data using the method of bins as described in the Sandia-Laboratory report referenced in Appendix II in 24 September 1980 Federal Register. The power output curve for an interconnected SWECS shall be determined using the required power conditioning SWECS subsystem as specified by the SWECS manufacturer.

(2) Standard Mean Power Output, Standard Operating Time Factor and Standard Annual Energy Production. Using the SWECS power output curve from paragraph (1) above, the SWECS standard mean power output, standard power operating time factor, and standard annual energy production shall be computed for the designated annual average wind speeds of 8, 10, 12, 14, 16, and 18 mph. The calculations shall be made in accordance with the following procedures:

(i) The frequency of occurrence [F(V)] for each designated average annual wind speed (V) shall be determined using V of one unit (1 m/s or 1 mph) and the Rayleigh distribution.

(ii) For each designated average annual wind speed (V), multiply the frequency of occurrence of each wind speed [F(V)] calculated in paragraph (2)(i) above, by the power indicated at that wind speed (V) in the SWECS power output curve developed according to paragraph (1) above.

(iii) The Standard Mean Power Output (kilowatts) for a designated average annual wind speed (V) shall be determined by the summation of the values calculated for each increment in paragraph (2) (ii) above.

(iv) The Standard Annual Energy Production (kilowatt hours) for a designated average annual wind speed (V) shall be determined by multiplying the Standard Mean Power Output (kilowatts) calculated in paragraph (2) (iii) above, by 8760 hours.

(v) The Standard Operating Time Factor at each designated average annual wind speed (V) shall be determined by:

(A) Adding those values of the frequency of occurrence calculated in paragraph (2)(i) above, for all wind speeds where the power produced by the SWECS is zero; and

(B) Subtracting the sum of (A) above from one; and

(C) Multiplying the result of (B) above by 100.

(3) All reported test data involving SWECS power output shall be corrected to a standard air density of 1.2 kg/m^3, using the following equation:

$$Ps = (1.2/Dm)Pm$$

Ps = power output (kilowatts) corrected to a standard air density of 1.2 kg/m^3.

Pm = measured power output (kilowatts).

Dm = air density (kilograms per cubic meter) at the test site.

(4) Reference wind data shall be corrected to the center of the SWECS rotor height using the following equation.

$$Vr = Vm(Zr/Zm)^{1/7}$$

Where:

Vr = Corrected wind speed (miles per hour) at Zr (feet).

Vm = Measured wind speed (miles per hour) at Zm (feet).

Zr = Height (feet) above ground level to the center of the SWECS rotor.

Zm = Height (feet above ground level where the referenced wind speed (Vm) or (miles per hour) was measured.

There are three testing methods considered to obtain reliable data on the performance of SWECS. The first of them is atmospheric testing, which means that the wind machine is mounted on a tower and is operated in the atmosphere. This is the only allowable method for initially qualifying a wind machine under RCS or for introducing a major modification to one that has been previously qualified. It is the preferred testing method because it provides field operation and experience involving gusting temperature fluctuations, and tests all components of the SWECS.

The second method for testing involves towing tests. These are useful because they allow the wind machine to cycle through any wind speed for the desired length of time. This method involves mounting the wind machine on a short tower secured to the towing device and driving a vehicle at chosen speeds to simulate atmospheric winds.

The third method involves wind tunnel testing. This method is currently economically impractical due to the size of the tunnel required to meet the requirements, but is included in case it is used by a manufacturer.

For each of the testing methods mentioned above, there are requirements dictating the way in which the tests shall be conducted. They are discussed below.

(1) Atmospheric Test. Data on the SWECS performance and safety characteristics as required in this standard shall be obtained by atmospheric testing. Data to validate changes in the SWECS model design, which do not significantly impact the performance or safety of the SWECS, may be obtained by using the test methods as specified in (1),(2), or (3) below. Data to validate changes that do significantly affect performance and/or safety of the SWECS shall be obtained only by the test method specified in (1) below. When an atmospheric test is used, the following requirements shall apply:

   (i) The atmospheric test shall be conducted for a period of time sufficient to provide not less than 25% of the SWECS Standard Annual Energy Production at 14 mph. The test period shall not be less than three months.

   (ii) For both horizontal and vertical axis wind turbines, the SWECS rotor shall be located on a tower or support such that the minimum blade clearance above ground level is 8.1 ft.

   (iii) Any obstructions to the flow of air into or from the SWECS rotor which are not an integral part of the SWECS and have a total projected frontal area exceeding 25% of the rotor-swept area shall not be permitted within a distance of 5 rotor diameters (of the SWECS being tested) in any direction of the SWECS rotor.

   (iv) A SWECS designed for interconnection shall be tested using a utility system as the electric load.

(2) Towing Tests. When a towing test is used to validate a change in SWECS model configuration, the following requirement shall apply:

   (i) The anemometer location shall be such that the wind speed at the anemometer shall be within ± 2-1/3 mph of the wind speed at the center of the SWECS rotor.

(ii) Any obstructions to the flow of air into or from the SWECS rotor that are not an integral part of the SWECS and have a total projected frontal area exceeding 25% of the rotor-swept area shall not be permitted within the cylinder of projection of the SWECS rotor.

(3) Wind Tunnel Tests. If a wind tunnel test is used to verify a SWECS model design change, the following requirements shall apply:

(i) The SWECS rotor shall be located at the center of the cross-section area of the wind tunnel test section; and

(ii) The SWECS rotor swept area shall not exceed 30% of the free stream cross-section area of the wind tunnels test section.

(There are some other details involved in the performance testing of SWECS. These details covered are:

- Yaw motion
- Data Analysis

The purpose of these topics is to standardize the tests so that the data collected through testing will have a comparable meaning from machine to machine. The description of this standardization for these details are as follows:

Yaw motion requirement for horizontal axis SWECS. During the conduction of the tests described in paragraph (1) through (3) above, the SWECS shall be free to operate in its normal configuration in yaw for all motions ± 90° from the nominal wind direction wherever possible. If physical limitations of the test setup make this impossible or unsafe, a physical limitation on the amount of yaw motion is permitted.

Data analysis requirements. Performance testing shall be conducted over a range of wind speeds including, but not limited to, the range specified under discussion "Power Output Curve." The bin width shall not be greater than 2.2 mph. The wind duration at each bin in the interval must satisfy at least one of the following conditions:

- The wind speed must be recorded in the given bin for a duration not less than 5% of the total test duration; or
- The wind speed must be observed in the given bin for at least one minute; or
- The wind speed in the given bin must have been recorded for at least 100 independent observations.

7.5.2 Instrumentation.

The instrumentation used to conduct the tests specified in this section shall meet the following requirements:

- The anemometer system used to measure wind speed shall have an error no greater than ±10% of the reading over the range 4.5 to 45 mph and an anemometer distance constant equal to or less than 16 ft.
- Power output of the SWECS shall be measured or calculated from measured values with an error no greater than ±5%.

- All readout or recording devices shall have an error no greater than ±5% of reading, a frequency response of at least 0.1 Hz and shall be capable of recording or displaying essentially simultaneous wind speed and power output data.
- The anemometer shall be located not less than one and not more than 10 SWECS rotor diameters from the center of the SWECS rotor if the anemometer is not located at or near the height of the center of the SWECS rotor (±1.5 rotor radii). The anemometer shall be located not less than 3 and no more than 10 SWECS rotor diameters from the center of the SWECS rotor if the anemometer is at or near the height of the center of the SWECS rotor (±1.5 rotor radii) and in no case shall tests be performed when the anemometer is located downwind from the rotor (when the wind direction is within ±45° of a line drawn from center of the rotor to the anemometer). All wind speed values must be corrected to the height at the center of the SWECS rotor using the locally measured wind shear profile or, if wind shear measurements are not available, the data shall be corrected using the following equation:

$$Vr = Vm(Zr/Zm)^{1/7}$$

Where:

Vr = Corrected wind speed (miles per hour) at Zr (feet).

Vm = Measured wind speed (miles per hour) at Zm (feet).

Zr = Height (feet) above ground level where the reference wind speed (Vm) (miles per hour) was measured.

(v) Electrical power instrumentation shall measure the power delivered from the SWECS, minus any power used by the SWECS for such components as control subsystems and power conditioning equipment.

(vi) All working instruments used in the conduct of these tests shall be calibrated (per the instrument manufacturer's recommendations) to reference standards which are traceable to the National Bureau of Standards. The calibration may be accomplished by the instrument manufacturer or any other organization which has appropriate experience and equipment to accomplish the calibration process. Further, during the conduct of any required tests, the instruments being used shall have been calibrated within the designated calibration time interval recommended by the instrumentation manufacturer.

Testing organization certification. The organization conducting any test outlined in this standard shall self-certify that it has met all the testing requirements stated in this standard. A signed statement of compliance with this standard shall be kept on file with the SWECS manufacturer and the organization that conducted the test for a period of 5 years.

7.6 INSPECTOR'S CHECKLIST AND DISCUSSION

1. **Ensure that the foundation, if deemed a "standard foundation," has been installed according to detailed installation instructions, as provided by the manufacturer. (See Figs. 7-2, 7-3, 7-4; Section 7.7).**

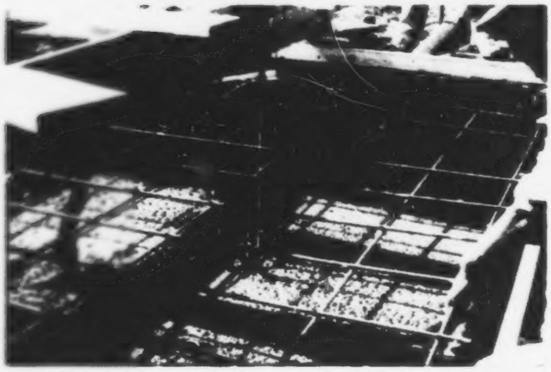


Figure 7-2. Foundation Preparation

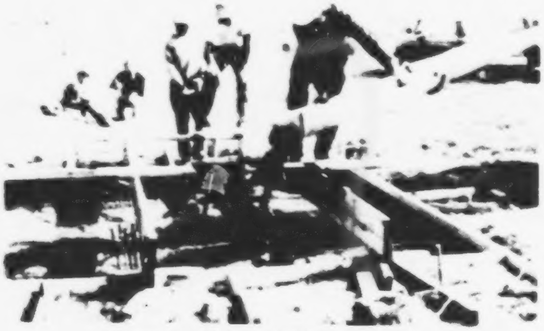


Figure 7-3. Foundation Pouring

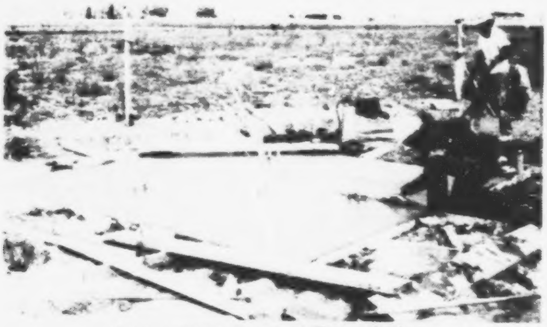


Figure 7-4. Poured Foundation

The manufacturer will have designed a foundation for the dynamic and static loads which each model wind turbine generator will encounter. It is the duty of the inspector to verify that the manufacturer's specified foundation has been installed and a copy of the specifications retained. In situations where local building codes apply, the local building inspectors will have checked the foundation in the various stages of construction, as after excavation, placement of forms and iron, and after pouring of concrete.

2. **Ensure that the adequacy of the foundation for the application has been determined based upon an analysis of the loads that the foundation will bear; in unusual soil conditions (sand, loam) this could require a site-specific soil analysis and determination of specifications for the foundation. (See Fig. 7-5; Section 7.7).**

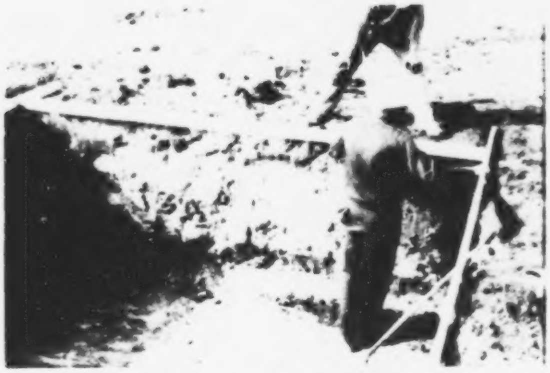


Figure 7-5. Foundation Specifications

In situations where the load bearing capacity of the soil is below that soil capacity specified as suitable for the SWECS foundation, a modified foundation must be designed that will support the loads imposed by the SWECS in the soil encountered. The purpose of this is to prevent the installation of SWECS on a foundation that cannot maintain its integrity given the loads that it will encounter through the life of the SWECS.

3. **Ensure that all bolts on the tower foundation are tight according to specification; ensure that there are no omitted bolts. (See Fig. 7-6; Section 7.7).**

Figure 7-6. Tower Anchorage

The inspector should assure that the foundation bolts have been properly attached to the foundation, which requires installer assurance that the bolts are the size and depth specified by the manufacturer. He must then check that the attachment to the tower is as specified by the manufacturer and that they are tightened down to proper torque, if specified.

4. **Ensure that tower bolts are tightened according to the manufacturer's specification. (See Fig. 7-7; Section 7.7).**

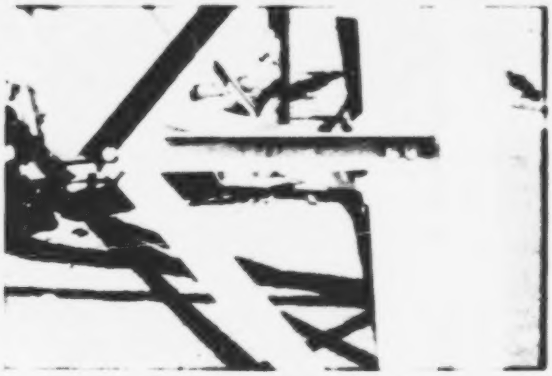


Figure 7-7. Tower Assembly

An inspector must check the tower to assure there are no missing or loose bolts, and that the bolts are installed to manufacturer's specification.

5. **Verify that the tower is a model specified by the manufacturer for the wind energy device used, when operating in the local wind conditions. (See Fig. 7-8; Section 7.7).**

Figure 7-8. Tower Specifications

The inspector must check that the manufacturer, model number, size, and type of tower are as specified by the SWECS manufacturer. Because static and dynamic loading on the tower by the wind turbine generator (WTG) creates a critical interface, this interface must have been checked by the manufacturer and verified by him that the system in compatible.

6. **For towers employing guy anchors only, ensure that all guy connections are tight and that anchors are installed per manufacturer's specification. (See Figs. 7-9, 7-10; Section 7.7).**

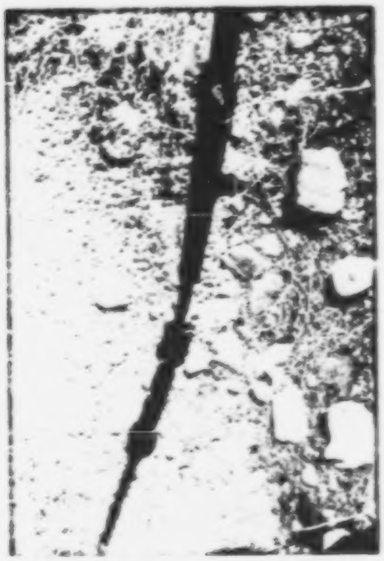


Figure 7-9. Guy Wire Anchorage

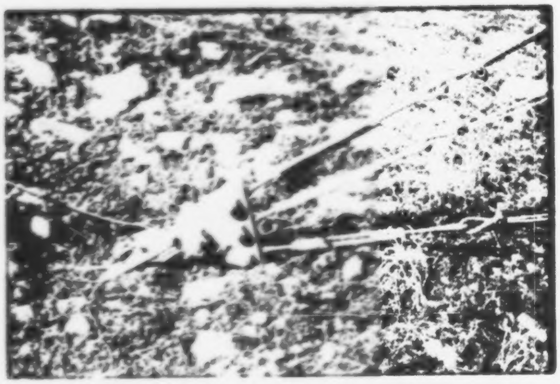


Figure 7-10. Guy Wire Connection

The strength and size of guy wires and specification for the ground anchors, when a part of the tower, must be to manufacturer's specifications to handle the static and dynamic loads imposed on them. The inspector should check that the installed system meets the SWECS manufacturer's specifications.

7. **Ensure that spacing and tensioning of the guy wires, in case of a guyed tower, is according to the SWECS manufacturer's specification. (See Figs. 7-11, 7-12; Section 7.7).**

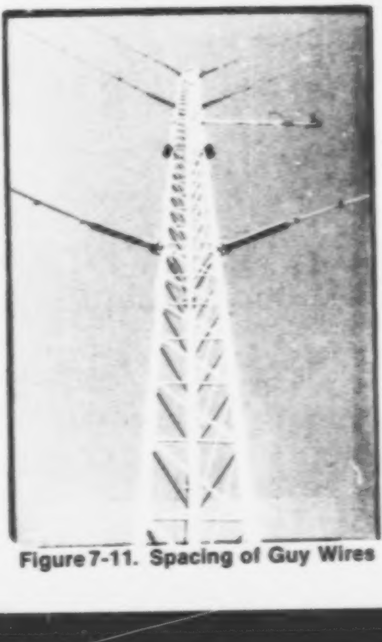


Figure 7-11. Spacing of Guy Wires

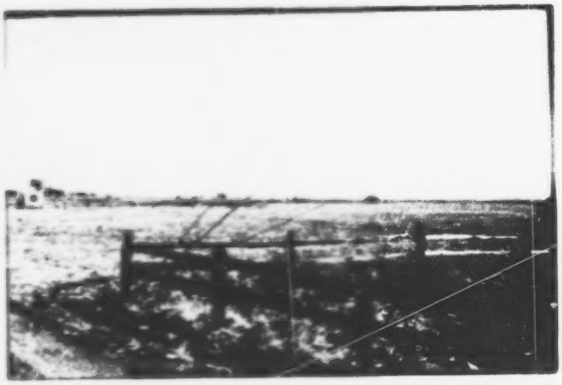
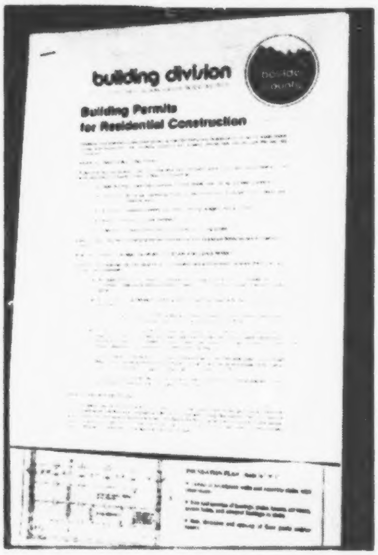


Figure 7-12. Tensioned Guy Wire

BEST DOCUMENT AVAILABLE

The spacing of guy wires determines the load carrying requirement for each guy in a SWECS installation; therefore, the spacing pattern on the ground and on the tower should be to manufacturer's specifications. Tensioning of guy wires determine the dynamic interaction between the WTG and the tower, and as such needs to be done to manufacturer's specification. The installers should provide assurance that this requirement has been met.

8. **Ensure that the SWECS has been installed according to the area and set-back requirements of local codes governing wind energy devices, accounting for any variances which may have been obtained. In case of non-specific codes, the SWECS should have been installed such that during operation, no part of the SWECS extends over a property line or utility easement, or infringes upon local clearance requirements for an overhead utility line. (See Fig. 7-13).**



building division

Building Permits for Residential Construction

Figure 7-13. Local Code Regulating SWECS Setback

The SWECS must not infringe upon any easements or violate local ordinances in its operational cycle. In the absence of any codes, the SWECS should not extend over property lines or utility easements and should not infringe upon the local clearance requirements for an overhead utility line.

9. **Ensure that the WTG is adequately mounted to the tower, according to the manufacturer's specification, and that the detailed instructions for the assembly, installation, and checkout of the SWECS have been followed by the installer. (See Figs. 7-14, 7-15; Section 7.7).**

Figure 7-14. Setback Requirements

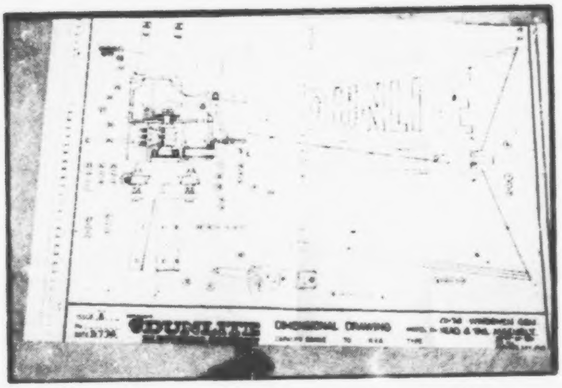


Figure 7-15. WTG Mounting Specifications

The installer should assure that the WTG has been assembled and mounted on the tower as per manufacturer's specifications. The inspector should note the installer's verification.

10. **In the case of interconnected SWECS, ensure that a lockable disconnect switch is installed to insure a utility lineworker's safety. Verify that the enclosed box is lockable. Ensure that the circuit if open when the disconnect switch is engaged. (See Fig. 7-16; Section 7.7).**

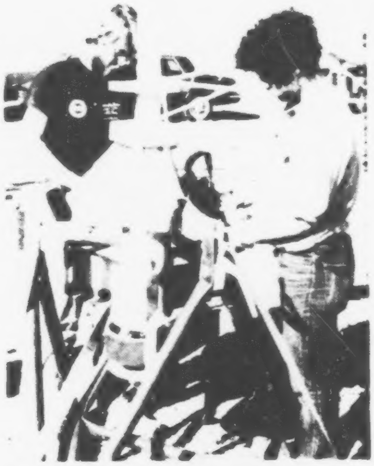


Figure 7-16. Mounting WTG to Tower

In order to provide for lineman safety, a lockable disconnect box must be installed in each SWECS and be available to utility at all times so that the SWECS can be isolated from the utility system for line work. The installer should verify the installation, operation, and access to this device.

11. **Verify that lightning protection has been installed according to the manufacturer's specification. (See Fig. 7-17).**

Figure 7-17. Lockable Disconnect Switch

Lightning protection should be available per manufcturer's specifications to National Electric Code (NEC) Article 280 or as specifically designed for the SWECS. Conformance to manufacturer's specifications should be verified.

12. **In the case of intertie, ensure that an automatic fused/circuit breaker disconnect is installed between the intertie point and the WTG. (See Fig. 7-18; Section 7.7).**

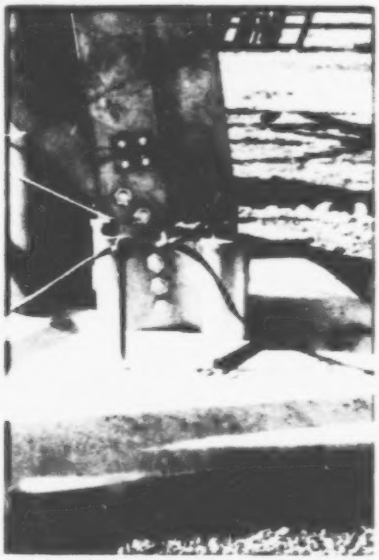


Figure 7-18. Lightning Protection

An automatic circuit breaker must be installed and capable of isolating the SWECS from the utility in the event of a condition in the line which could trip a circuit breaker at the rated amperage of the line. The position of this breaker between the SWECS and the utility must be verified and isolation of the two systems upon tripping of the breaker must be assured.

13. **Ensure that control units have been installed according to the manufacturer's specification. (See Fig. 7-19; Section 7.7).**

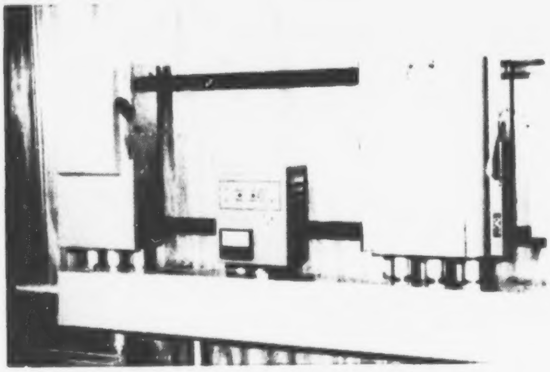


Figure 7-19. Circuit Breaker (middle box)

The control unit specified for the SWECS by the manufacturer must be verified by the inspector to be the one installed by the installer. Capacity and type should be verified by the inspector.

14. **Ensure that the wire size and type satisfy NEC specifications with respect to length of run, capacity, and environmental exposure. (See Fig. 7-20).**

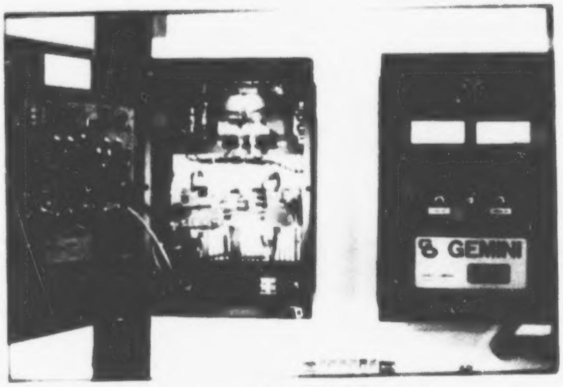


Figure 7-20. Control Unit

The electrical wiring must meet local codes or NEC, and the inspector should verify that the electrical component of the installation has satisfied the local building inspector and that the installer has performed to manufacturer's specification.

15. **In case of intertie, ensure that the interconnection of the wind energy device to the utility line is on the user's side of the utility revenue meter. (See Fig. 7-21).**

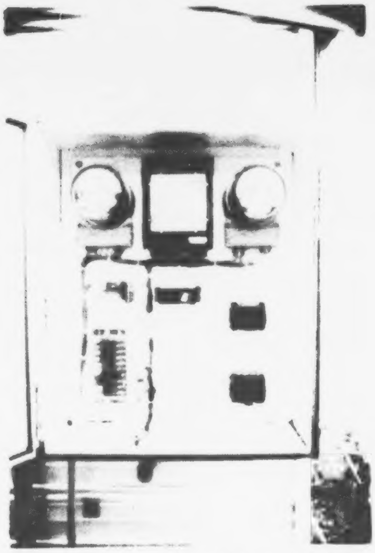


Figure 7-21. Electrical Use Meters

The inspector should verify that the installation of the intertie has been made on the user's side of the utility billing meter.

16. **Check that the SWECS tower subsystem label is attached in an accessible location.**

A label should appear on the tower in a visually accessible location which has the following information:

- Equipment weight of the tower subsystem
- Manufacturer's name and address
- Model number
- Serial number
- The following tower warning label or equivalent: "Warning: Installation and Maintenance of This Product Near Power Lines is a Danger. For Your Safety Follow the Installation and Maintenance Instructions."

The inspector should verify this labeling information.

17. **Check that the SWECS housing label has been attached to the WTG in an accessible location.**

A label should appear on the WTG with the following information:

- Maxium design SWECS power output (kW) and the wind speed at which it is achieved (meters per second and miles per hour)
- Nominal voltage (volts) and maximum current (amperes)
- Equipment weight (kilograms and pounds) above the foundation. Tower weight shall be included in the total if the tower is installed simultaneously with wind turbine generator.
- Survival wind speed (meters per second and miles per hour)
- SWECS manufacturer's name and address
- SWECS model number
- SWECS serial number
- The following statement or equivalent: Warning: Installation and Maintenance of This Product Near Power Lines is a Danger. For Your Safety Follow the Installation and Maintenance Instructions.

In addition, the power conditioning unit should contain the following information on a label:

- Maximum power input (kW), rated voltage (volts) and rated current (amperes) of the power conditioning subsystem
- Manufacturer's name and address
- Serial number

And finally, normal and emergency shutdown procedures should appear on a label at ground level. The inspector should verify existence of this information.

7.7 SAMPLE INSTALLATION MANUAL

This is an example of a typical installation manual that would be provided by a wind system manufacturer to aid in the installation of the system. The manual was created for the Department of Energy at its Rocky Flats Small Wind Energy Test Center as part of a prototype development program. These installation instructions are for a single, specific prototype unit and should not be utilized for any other wind system.

The manual is reproduced in its entirety with the exception of Figures 1, 3, 5, 7, 10, 14, 16, and drawings. These were omitted because they were unavailable for reprint; however, they would appear in a complete installation manual.

SAMPLE INSTALLATION MANUAL

The Wind Turbine Generator, WTG, as supplied to the customer, consists of the following items:

A. One lower tower pipe section with attached base plate and gudgeon pin.

B. One three-flanged upper tower section.

C. Six 1-in. diameter guy wires precut and assembled to proper length, with flange tangs at their upper ends and turnbuckles at their lower end.

D. One preassembled rotor head assembly (see drawing) consisting of:

  a. A supporting frame with yaw shaft and yaw bearings.

  b. A generator - 20-hp,three-phase induction motor and frame.

  c. A gear reducer - ratio 17:1 with internal backstop.

  d. A rotor drive shaft with two spherical roller bearings.

  e. A rotor hub held to the drive shaft by a compression clamp.

  f. A power slip ring assembly with brushes rated at 90 amps.

  g. A steel shipping stand, supporting the assembly.

E. A three-part fiberglass nacelle.

F. A carbon epoxy rotor flexbeam, pretwisted 16° with 8° precone.

G. Two untwisted, fiberglass rotor blades of constant chord and thickness, with attached aluminum root fittings.

H. A 64-tooth gear on the generator rotor and a electromagnetic pickup for rotor speed detection.

I. A solid state speed detector preset to cut in at generator speeds in excess of 1900 rpm and cut out at speeds below 1800 rpm.

J. The following items are included on the prototype, only:

  a. A thirty-circuit slip ring assembly on the drive shaft wired to a similar thirty-circuit slip ring assembly on the yaw shaft for instrumentation. Max current 10 amps.

b. A hydraulic disc brake assembly on the rotor drive shaft.

c. A hydraulic master cylinder to provide brake pressure.

d. An electric (12 VDC) actuator to operate the master cylinder.

In addition, the following hardware is provided to the customer to assist in raising and lowering of the WTG at his site, without the need for crane service:

A. A five-ton hand winch (optional electric)

B. A jib boom

C. A snatch block for the jib boom

D. A two-sheave pulley

E. Approximately 125 ft of 1/2 wire rope

It is the purpose of this section to assist the customer in the assembly of the WTG system, resulting in a unit which may then be erected and operated at his site.

Section 1.1 Foundation and Ground Anchors (Ref. Dwg 1740-16)

The WTG is supported by a two-piece,ten-in. diameter schedule 10 steel pipe standing on a reinforced concrete pier and supported by six one-in. guy wires attached in pairs to the three ground anchors (Fig. 1). The tower and guy wire loads during the erection procedure and during high wind operation must be transmitted to the soil through the foundation and ground anchors, which must be sized to accommodate these loads, which are depicted in Fig. 2. The local soil condition will dictate what the physical size of the ground support system must be.

Section 1.2 System Assembly - Ground Supports

1. Pour a reinforced concrete tower foundation (as required by local soil characteristics) with four 1-14 in.diamsteel anchor bolts imbedded as shown in Dwg. 1740-16.
2. Bury three ground anchors (physical size being dictated by local soil condition). For illustrative purposes, a typical ground anchor design for medium-soft clay is presented in Dwg. 1740-16.
3. The completed foundation and ground anchors are shown, for a typical installation in Fig. 3.
4. Pour a steel, reinforced pier for the winch base and the double sheave erection pulley anchor.

   For illustrative purposes, such a pier is shown in Fig. 4 for a medium-soft clay soil site.

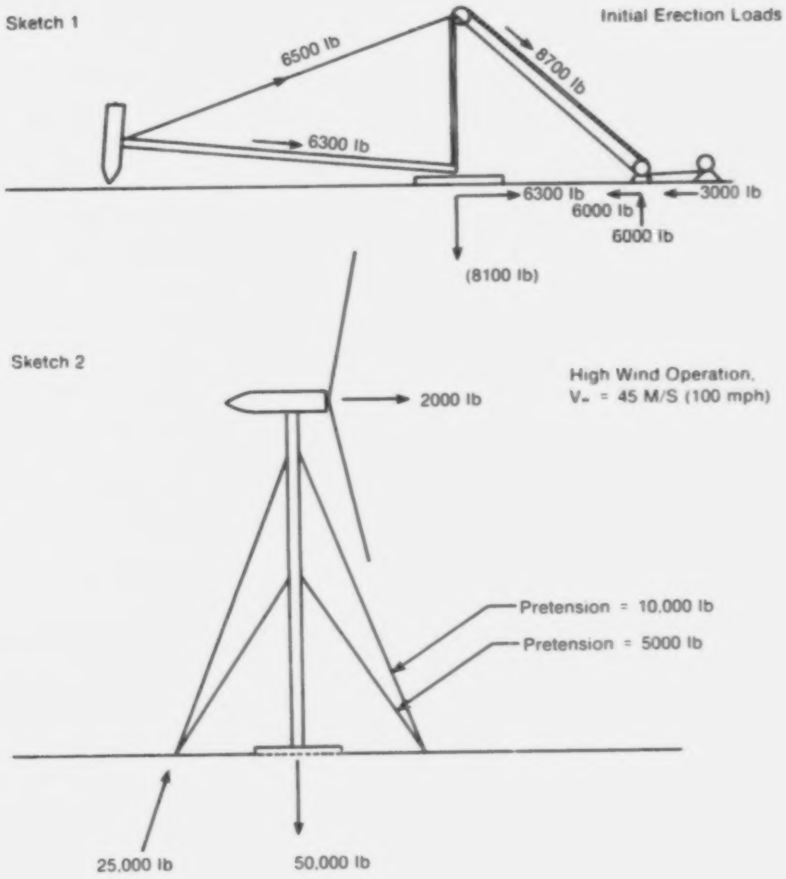

Sketch 1
Initial Erection Loads
6500 lb
8700 lb
6300 lb
6300 lb
6000 lb
3000 lb
6000 lb
(8100 lb)
Sketch 2
2000 lb
High Wind Operation,
V∞ = 45 M/S (100 mph)
Pretension = 10,000 lb
Pretension = 5000 lb
25,000 lb
50,000 lb

Figure 2. System Loads

Section 1.3 System Assembly- Tower (Ref. Dwg 1740-5)

The WTG system is to be completely assembled at ground level and then raised, as a unit, to its working height. Assembly is to be accomplished in the following sequence:

1. Install the tower base plate (Part No. 00146) over the four foundation anchor bolts.
2. Install the lower tower section (Part No. 96372), horizontally on the foundation, by sliding the tower's base pivot pin between the two sets of anchor bolts.
3. Apply conventional bearing grease to both ends of pivot pin.
4. Insert the two base retainers (Part No. 00144) over each pair of anchor bolts and over each pin end. Secure retainers with lockwashers and 1-1/4-6 hex nuts. Torque to 200 ft-lb (Fig. 5).
5. Prop up the lower tower section such that it is well supported and resting horizontally.
6. Swing the upper tower section (Part No. 00626) into place against the lower tower. Rotate the upper tower to align the flange bolt patterns.
7. Bolt upper and lower tower flanges together with 7/8-9 thru bolts, lockwashers and nuts. Initially install bolts in the 6 holes located at 2, 6, and 10 o'clock (see Fig. 6 for definition). Torque to 150 ft-lb

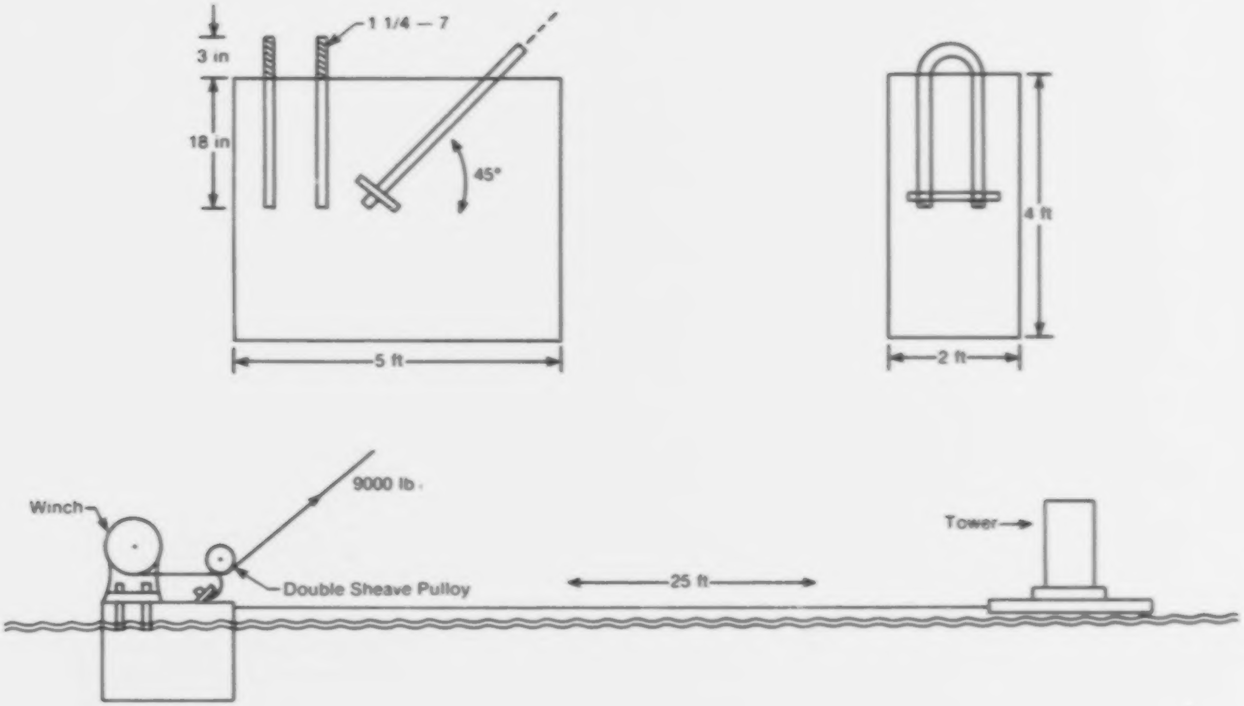

3 in
1 1/4 — 7
18 in
45°
5 ft
4 ft
2 ft
Winch
9000 lb
Double Sheave Pulley
25 ft
Tower

Figure 4. Pier for Winch and Double Sheave Pulley

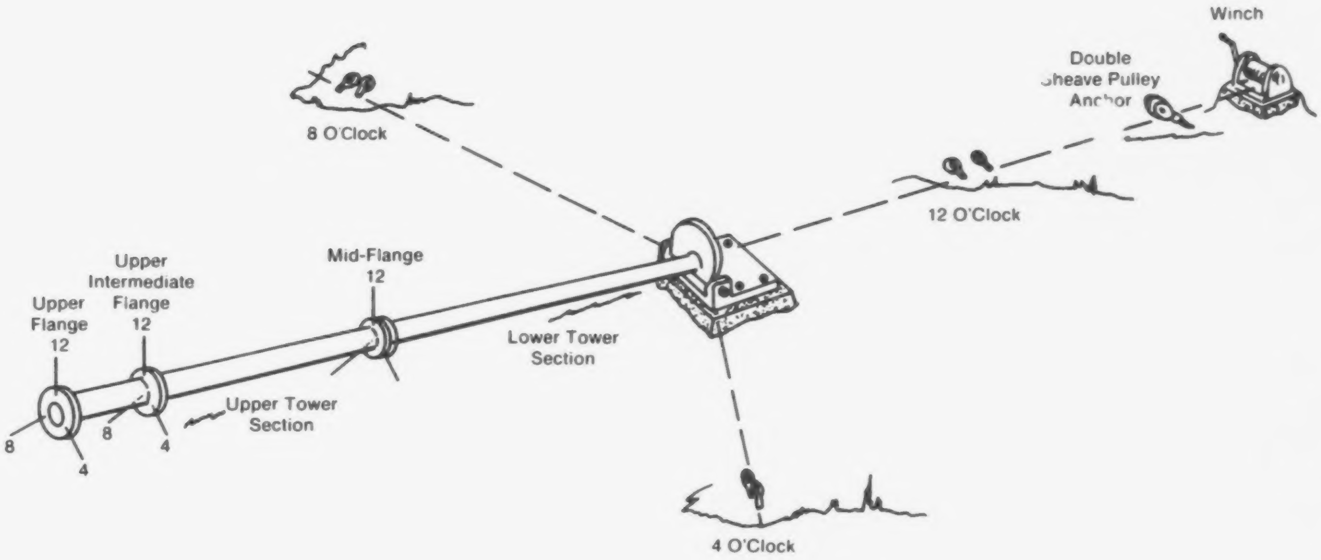

Winch
Double Sheave Pulley Anchor
8 O'Clock
12 O'Clock
Upper Intermediate Flange 12
Mid-Flange 12
Upper Flange 12
Lower Tower Section
Upper Tower Section
8
4
8
4
4 O'Clock

Figure 6. Orientation of Tower and Ground Supports During Installation

8. Install the three guy wire tangs (Part No. 96371-2) at the six holes located at 12, 4, and 8 o'clock, with 1-in. diam guy wires attached and tang bent toward the tower base. Secure with 7/8-9 thru bolts, lockwashers, and nuts. Torque to 150 ft-lb.
9. Similarly, at the intermediate flange on the upper section (about 7 ft from the top) install three guy wire tangs (Part No. 96371-1) with the longer 1-in. diam cables attached to the flange holes at 12, 4, and 8 o'clock. Secure with 7/8-9 thru bolts, lockwashers and nuts. Torque to 150 ft-lb.
10. Secure the guy wire turnbuckle, coming from the mid-flange's 4 o'clock position, to the inner ground anchor at the 4 o'clock position. Insert the turnbuckle's clevis pin through the ground anchor's eyebolt and secure with a cotter pin.
11. Repeat this procedure for the guy wire turnbuckle coming off the 8 o'clock flange position to the ground anchor on that side of the tower.
12. Secure the guy wire turnbuckles, coming off the upper-intermediate flange's 4 and 8 o'clock position, to the outer ground anchors on each side of the tower. Insert the turnbuckle's clevis pin through the ground anchor's eyebolt and secure with a cotter pin.
13. If tower is to be raised by crane service, skip steps 14-20 and resume procedure at step 21.
14. Attach the jib boom (Part No. 92066) to the tower base by sliding the boom clevis over the base's tongue. Secure with a 3/4-8 bolt and nut. Torque to 75 ft-lb.
15. Attach the guy wire turnbuckle, coming off the upper-intermediate flange's 12 o'clock position to the head fitting on the outer end of the jib boom. Secure with a cotter pin through the clevis pin. The tower-ground support system is shown in Fig. 7.
16. Install the hand winch (optional electric winch) on its foundation.
17. Install the single sheave pulley to the head fitting on the jib boom.
18. Install the double sheave pulley to the ground anchor.
19. Run 1/2-in. diam wire rope from winch through pulley system as per Fig. 8. Tie the free end of the cable off at the head fitting of the jib boom. The mechanical advantage of this system is 3:1.
20. Using an "A" frame with a chain fall, hoist the jib boom about 5 ft off the tower. Then, using the winch, raise it to a vertical position. This will cause the upper, 12 o'clock, guy wire to go taut.
21. Set hand winch to low speed and raise the tower until the intermediate, upper flange is 5 ft above the ground. Or using a crane with cables up against the underside of the upper-intermediate flange, raise tower until this flange is 5 ft above the ground.
22. Prop up the tower with an "I" beam or wood shoring as a safety precaution. The tower is now in position for the installation of the head assembly.

Section 1.4 System Assembly - Rotor Head (Ref. Dwg. 1740-3)

The rotor head is completely assembled on its shipping stand, except for the rotor blades, then inserted into the tower at ground level. The blades are then attached and the system is raised, as a unit. to its working height. The sequence of events to arrive at the point of erection is as follows:

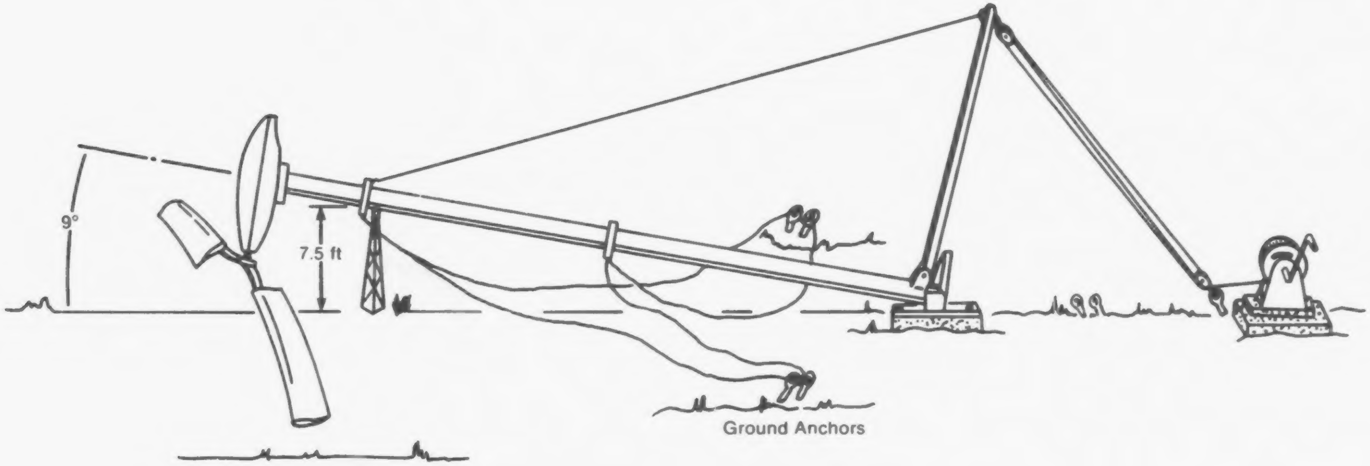

9°
7.5 ft
Ground Anchors

Figure 8. 8 kW Prototype Tower Head at Working Height

1. Ref. Dwg. 1740-3. Separate the two rectangular hub halves by removing the 10 3/4-10 hex nuts and bolts and lifting away the hub front (Part No. 00160).
2. Route the instrumentation cables (coming through the hollow drive shaft) out through the milled slot in the drive shaft nipple.
3. Install the carbon epoxy flexbeam over the drive shaft nipple, with the beam coming away from the head assembly.
4. Install bolts 1, 5, 6, and 10 (see Fig. 9 for definition) through the hub rear (Part No. 00629) then install the upper and lower spacer shim (Part No. 00158) over the bolts (make sure that the thin brass shims are also included). Install hub front over bolt and secure with lockwasher and 3/4-16 nuts. Temporarily torque to 15 ft-lb.
5. Install arm (Part No. 00631) with the connected pendulum arm assembly (Part No. 00630) to the hub front as shown in Dwg. 1740-4. Secure with 3/4-16 lockwasher and nuts. Temporarily torque to 15 ft-lb.
6. Install the remaining 3/4-16 bolts, lockwasher, and nuts to secure the hub halves.
7. Following a sequence of 3, 8, 4, 7, 2, 9, 5, 6, 1, 10 (Fig. 9) torque the 3/4-16 nuts and bolts to 108 ft-lb in increments of about 30 lb-ft.
8. Route the instrumentation cables to the small enclosure on the hub front and connect to cables coming off the flexbeam.
9. Tie the pendulum arm assemblies (Part No. 00630) together and back with a piece of rope to prevent their moving during the assembly procedure. The rotor head assembly is now ready for installation in the tower.

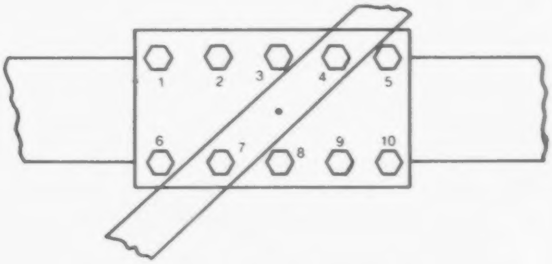


Figure 9. Rotor Hub Bolt Definition

Section 1.5 System Installation - Rotor Head on Tower

1. Remove the rotor head assembly from the shipping stand. Rotate and support it, such that the yaw shaft is horizontal, with a fork truck or small crane. See Fig. 10.1.
2. Move head assembly into alignment with the tower about 1 ft away from the upper flange.

3. With electrician snake route 3 conductor power cables through side hole at base of tower and up tower. Similarly route six instrumentation cables through second hole at tower base to top. Also route two conductor DC cable for brake actuator.
4. Connect three power cables coming up the tower to six power cables coming from the yaw shaft slip ring assembly. Red-red, black-black, white-white. Insulate.
5. Connect two conductors of brake actuator cable coming up the tower to two cables coming off the slip ring assembly as labelled. Insulate.
6. Connect instrumentation cables coming up the tower to their mates coming off the yaw shaft instrumentation slip rings as numbered (i.e.,1-1, 2-2, 3-3 etc).
7. The tower, cabling, and rotor head yaw shaft appear in Fig. 10.2.
8. Install two "U" bolts, one over power cables and one over the instrumentation cables, and out through two sets of holes located about 5 ft from tower top. Secure "U" bolts to tower, temporarily, by hand tightening nuts.

   NOTE: These "U" bolts will act as cable clamps when the unit is in the vertical position, taking the weight of the cabling off the yaw shaft brush housing.

9. Carefully insert the yaw shaft into the tower (Fig. 10.3) taking care that the yaw shaft and tower remain aligned to prevent binding between the two. As the yaw shaft is inserted into the tower, continuously take up the slack in the power and instrumentation cables to prevent their bunching at the top of the tower and consequently being crushed by the yaw shaft.
10. Align head assembly flange bolt pattern with upper tower flange pattern and secure with 7/8-9 hex head thru bolts, lockwasher,and nuts. Torque to 150 ft-lb.
11. Now tighten the nuts on the cable clamp "U" bolts to 10 in.-lb.
12. Install the lower yaw bearing grease fitting through the access hole provided in the tower.
13. Using the winch (or crane) raise the tower, slowly, while the fork lift truck supports the head assembly, to a height of about 8 ft. As this is being done, the head assembly will want to swing hub down. Care must be exercised to prevent the flexbeam from hitting the ground.
14. Remove the fork lift truck (or small crane) from the head assembly.
15. Continue the power hookup per Fig. 11.
16. Continue the instrumentation hookup per Fig. 12.
17. Determine the proper power hookup which will result in a clockwise rotor rotation, when looking from the generator toward the rotor, as follows.
    a. Connect BIDDLE PHASE AND DIRECTION meter to the three power cables coming from the WTG at the fuse box in the control room per Fig. 13.
    b. Have someone watch the meter while someone else turns the rotor by hand [it will only turn in the proper (CW) direction]. Note the direction in which the needle deflects as the rotor is initially turned.
    c. Now connect the three power cables coming from the utility, at this switch, to the BIDDLE meter.
    d. Turn power on to the switch and observe the needle deflection. The needle should deflect in the same direction as during step b above. If it does not, then reverse any two power leads coming into the switch and try again. It should. now, deflect in the same direction as during step b.

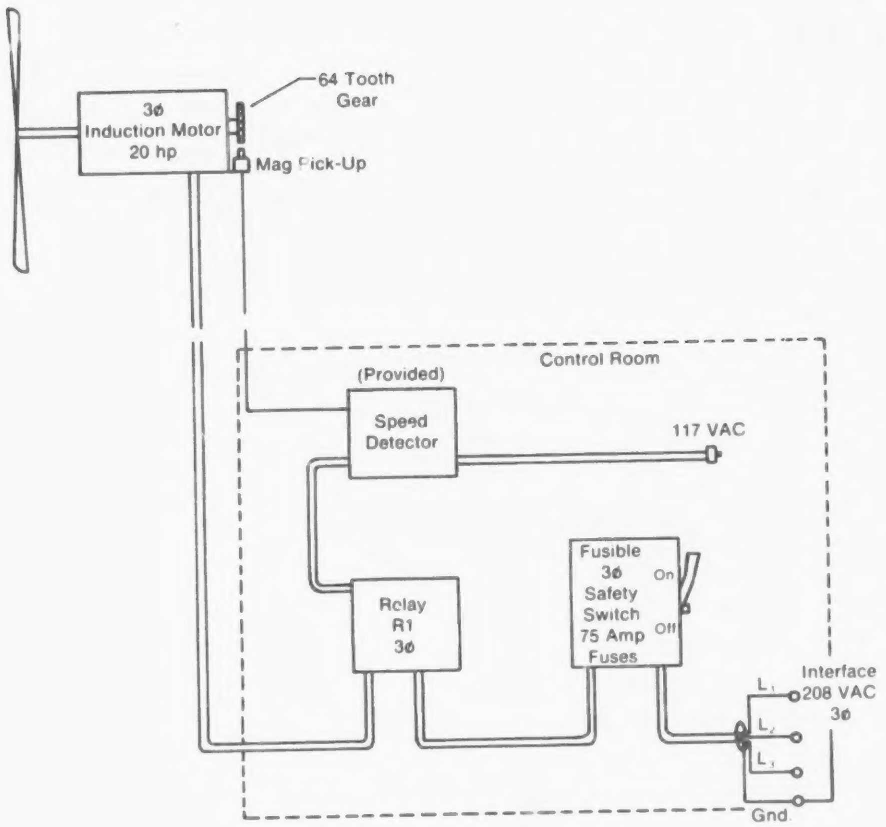
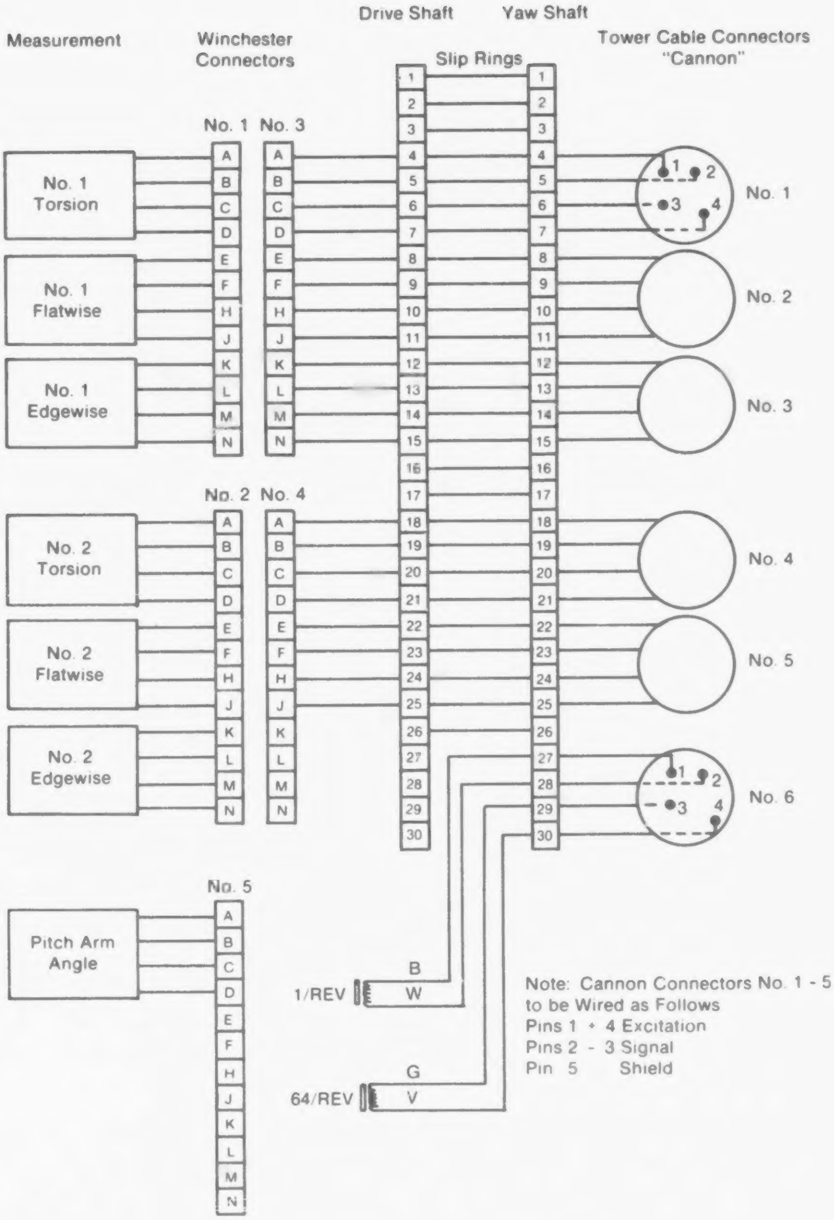

3φ
Induction Motor
20 hp
64 Tooth Gear
Mag Pick-Up
Control Room
(Provided)
Speed Detector
117 VAC
Relay R1 3φ
Fusible 3φ Safety Switch 75 Amp Fuses
On
Off
Interface 208 VAC 3φ
L1
L2
L3
Gnd.

Figure 11. 8 kW Prototype WTG Electrical Hook-Up


Measurement
Winchester Connectors
Drive Shaft
Yaw Shaft
Slip Rings
Tower Cable Connectors "Cannon"
No. 1
No. 3
No. 1 Torsion
No. 1 Flatwise
No. 1 Edgewise
No. 2
No. 4
No. 2 Torsion
No. 2 Flatwise
No. 2 Edgewise
No. 5
Pitch Arm Angle
A
B
C
D
E
F
H
J
K
L
M
N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
No. 1
No. 2
No. 3
No. 4
No. 5
No. 6
1/REV
B
W
64/REV
G
V

Note: Cannon Connectors No. 1 - 5
to be Wired as Follows
Pins 1 + 4 Excitation
Pins 2 - 3 Signal
Pin 5 Shield

Figure 12. Instrumentation Schematic

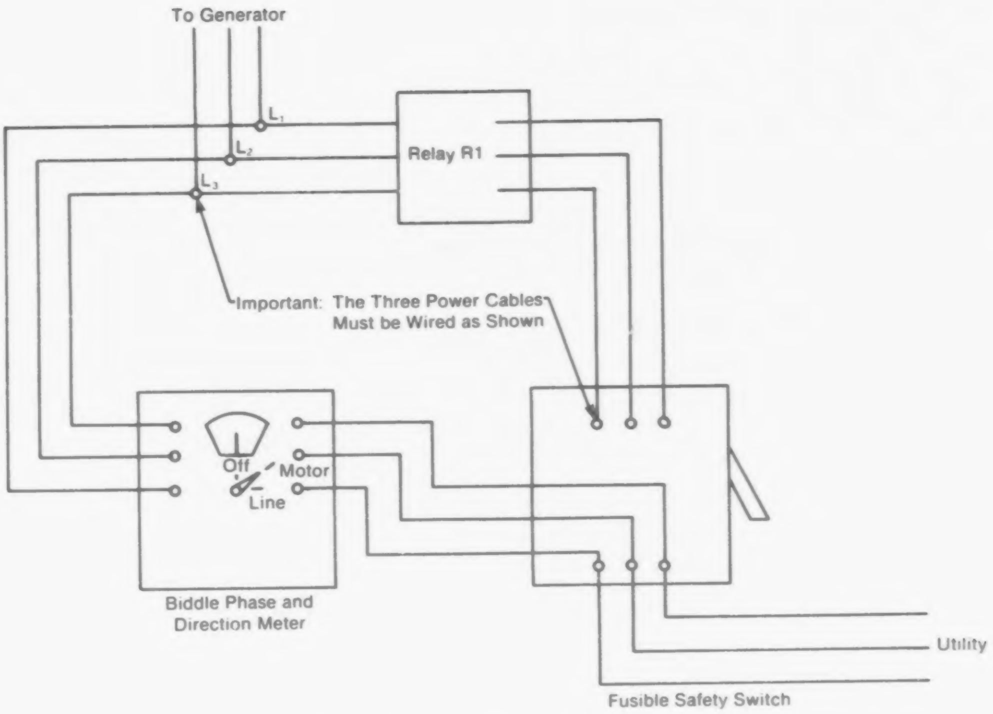

To Generator
L1
L2
L3
Relay R1
Important: The Three Power Cables Must be Wired as Shown
Off
Motor
Line
Biddle Phase and Direction Meter
Utility
Fusible Safety Switch

Figure 13. Determining Line Polarity

The system is now ready for blade installation.

Section 1.6 System Assembly - Rotor Blades (Ref. Dwg. 1740-4, 1740-8)

1. Locate flexbeam #1 (it is numbered) and blade #1 (single stripe).
2. Orient the blade such that the leading edge is pointed towards the #1 pitch arm then slide the aluminum yoke on the blade root over the flexbeam outboard mounting pad. (See Fig. 10.4).
3. Hand press the 1 in. diameter stainless steel bushings through the yoke and flexbeam, utilizing tool #4 (provided) (Fig. 10.5).
4. Deflect blade either toward the leading or the trailing edge to cause other two holes to line up. Once these holes are aligned, press bushings through as explained in step 3.
5. Install 3/4-13 bolts through the three bushings. Install the flexstrap mount (Part No. 00162) over the 3 bolts then secure the mount to the blade yoke and flexbeam with lockwashers and nut. Torque to 75 lb-ft.
6. Repeat procedure with blade #2.
7. Install flexstrap between #1 pitch arm and blade mount. Secure at the blade mount with five Allen bolts, lockwashers,and nuts. Torque to 75 ft-lb.
8. Secure flexstrap at pitch arm with 1 1/2-12 elastic stop nut. Torque to 75 ft-lb. The pendulum weight will not compress due to an internal bushing providing the proper operating clearance.
9. Similarly install #2 flexstrap.

SECTION 2

SYSTEM ERECTION AND INITIAL RUN-UP

Section 2.1 Erection

The Wind Turbine Generator has been completely assembled at ground level and is now ready for erection to its working height utilizing either the winch system, described earlier, or an optional crane service. One word of caution regarding crane use to erect the tower. The tower base is not designed to accept large side-to-side bending loads during erection. Therefore, care must be exercised to insure that the crane lifts the tower straight, in a plane perpendicular to the base pivot pin. Side-to-side loads must be avoided.

For the prototype, only, conduct checks in items 1 & 2 prior to erection.

1. Check instrumentation functioning by bending the No. 1 blade in edgewise and flatwise directions and by twisting in torsion. Note output response of each strain gage and establish polarity.
2. Check rotor disc brake by actuating brake and attempting to turn rotor by hand. Release brake and insure that rotor is now free. Actuate brake for erection.

3. Select low speed on hand winch, then raise tower by turning drum (Fig. 14). Optional: Slowly raise tower by taking up the crane's cable, which is looped around the tower just below the upper, intermediate flange.
4. With the tower in a vertical position, secure the lower guy wire, coming off the mid flange's 12 o'clock position, to the inner ground anchor. Insert the clevis pin through the ground anchor's eyebolt and secure with a cotter pin. Tighten this turnbuckle.
5. If using the winch system, remove the upper guy wire from the jib boom. The weight of the jib boom must first be removed from the cable. This is done as follows:
   a. Connect a come-along between the thimble on the guy wire and the side hole on the jib boom head fitting (Fig. 14.5).
   b. Tighten come-along until the clevis pin on the turnbuckle of the guy wire can be removed from the boom's head fitting.
   c. Lower the jib boom to ground level by letting out the come-along cable (Fig. 14.6).
   d. Remove come-along.
6. Secure the upper guy wire coming off the upper intermediate flange's 12 o'clock position, to the outer ground anchor with clevis pin and cotter pin.
7. Tighten this turnbuckle.
8. Check tower to ensure that it is standing vertically. Tighten cables as necessary to straighten tower.
9. In incremental steps, tighten turnbuckles with 18-in. long wrench, until further tightening becomes impossible.
10. System is now ready for run-up (Fig. 1).

Section 2.2 Run-up

1. Check all electrical switches in the control room to determine that:
   a. Speed switch is plugged in and switched on.
   b. Fusible safety switch is on and receiving line voltage from the utility.
2. Release disc brake, allowing rotor to run up to 30-50 rpm. Take a data record.
3. Stop rotor with disc brake and check data to determine that all instrumentation is functioning properly. Especially check the rpm output as it is important to the operation of the speed switch.
4. If instrumentation checks OK, system is ready for run-up.
5. Release disc brake and allow rotor to accelerate while monitoring rpm. The speed switch should close the relay, R1, when the generator speed reaches 1900 rpm, thereby connecting the generator to the public utility resulting in a power-out reading on the watt meter. If it does not close the relay before the generator reaches a speed of 2100 rpm, then stop the rotor with the disc brake and determine the source of the problem.
6. If the relay closes at the proper generator speed (i.e.,1900 rpm), then leave system

online and monitor until wind drops causing a drop in power-out until the generator speed drops to 1800 rpm which is its synchronous, no power-out, speed. At this generator speed (1800 rpm), the speed switch should cause the rely, R1, to open, thereby disconnecting the generator from the grid. Should the relay, R1, fail to open and the generator speed drops and stays, below 1800 rpm, then switch the large fusible safety switch to OFF. Brake the rotor to a stop and find the cause for the malfunction.

7. The system functions properly if the speed detector causes the relay, R1, to close at speeds in excess of 1900 rpm and to open at speeds below 1800 rpm. Once the system is observed to operate properly it may be left unattended for prolonged periods of time operating automatically.

SECTION 3

SYSTEM DESCRIPTION AND MAINTENANCE

Section 3.1 System Description

The 8-kW Wind Turbine Generator (WTG) consists of a horizontal axis, two-bladed rotor driving a 20-horsepower induction rotor through a 17:1 step-up transmission. The system is completely self-regulating in rotor blade pitch and in nacelle yaw. The rotor is 31 feet in diameter with blade of NACA23112 airfoil series (Fig. 1). The initial non-rotating blade angle is preset and nonadjustable at -16 deg which is defined as a 16 deg deflection of the leading edge from the plane of rotation towards nacelle (Fig. 15).

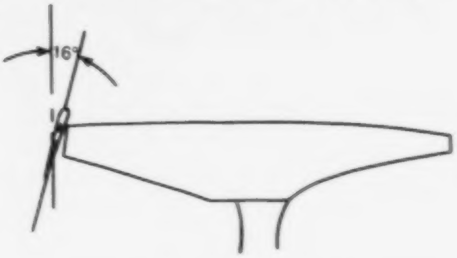


Figure 15. Rotor Blade Start-Up Angle

This initial blade angle of 16 deg allows the rotor to self-start in relatively light air of 7 mph. Once the rotor begins to turn, the blade pitch angle is automatically varied by the action of the pendulum twisting the flexbeam, to be increasingly twisted, until at 106 rpm (the rotor design speed), the flexbeam has been twisted a full 16° such that the blade angle relative to the rotor plane is 0°. This is the optimum angle for power output. If the rotor were free to run at high wind speeds (no power being taken out) then the rotor speed would increase, causing a simultaneous increase in the twist angle of the flexbeam until a point is reached where the blade pitch angle is approximately +6° causing the rotor to stall with a subsequent drop in rotor speed, preventing an overspeed situation.

The rotor shaft power is converted to electrical power by a 20-horsepower (15-kW) induction motor connected to a three-phase, 208-VAC, power grid. The motor's synchronous speed is 1800 rpm, corresponding to a rotor speed of 106 rpm. A speed detector, located in the control room at ground level, picks up a signal from a 64-tooth gear on the rotor armature and is set to connect the rotor to the utility whenever the rotor speed exceeds 1900 rpm and to drop it offline when the speed drops below 1800 rpm. Therefore, the rotor remains connected to the utility when it is in a generating mode (above 1800 rpm) and is disconnected when there is insufficient power available for generating (below 1800 rpm.)

The WTG should generate electricity at all wind speeds above 8.5 mph requiring no high wind shutdown or cut-out. In the event of a power outage, the unit (prototype) should be left free to rotate since the blade stresses are lower with the system rotating than with the rotor stopped. The rotor should be locked only when the unit is undergoing servicing or in the event of mechanical problems at the rotor head assembly.

Section 3.2 Maintenance

Section 3.2.1 Drive Shaft Bearings

The rotor drive shaft is supported by, and free to rotate in, two FMC spherical roller bearings. Thrust loads are transmitted to the frame through the larger (#22317) front bearing while the smaller (#22214) rear bearing transmits only radial loads. Since the drive shaft rotates, nominally, at only 106 mph, speedability is not a requirement for the lubricant but temperature extremes and loads must be considered.

1. Clean Alimite grease fittings on the right side of the head assembly frame and apply grease gun to bath fittings going to drive shaft. Apply 2 full strokes for the rear bearing and 3 full strokes for the forward bearing. Use lubriplate #630AA or equivalent. Repeat at 3-yr intervals.

Section 3.2.2 Geared Flexible Coupling FMC Type XR

1. Remove dryseal lubrication plugs from housing (they are 180° apart).
2. Rotate coupling so that holes are at 45° from vertical.
3. Insert tip of grease gun into top opening and pump in grease until lubrication overflows from the other fitting.
4. Replace both plugs and tighten.
5. Use lubriplate #630AA or equivalent. Repeat at 6-month intervals.

Section 3.2.3 FMC Gear Reducer

1. Drain oil by removing plug at lower right side of housing.
2. Replace plug when oil is fully drained.
3. Remove sight plug at right center of housing.
4. Remove breather pipe at top of housing.
5. Fill with appropriate oil until level with the bottom of the sight plug, approximately 2-1/8 gal.
6. Use SAE20 for temperatures below 32° F and SAE40 for temperature above 32° F.
7. Replace sight plug and breather pipe.

Section 3.2.4 Baldor Induction Motor

1. Clean tips of Alimite grease fittings on right side of frame.
2. Apply grease gun and use 2 full strokes per fitting.
3. Use Shell Dolium R or equivalent grease. Repeat at 3-yr intervals.

Section 3.2.5 Yaw Shaft Bearings

1. Remove upper nacelle.
2. Clean Alimite grease fitting in upper flange.
3. Apply grease gun and use 2 full strokes of Lubriplate #630AA or equivalent. Repeat at 3-yr intervals.
4. To grease the lower yaw bearing, the lower fairing must be removed.
5. Clean Alimite grease fitting which extends through the tower pipe, about 1 ft from the upper flange. Apply grease gun and use 2 full strokes of Lubriplate #630AA or equivalent grease. Repeat at 3-yr intervals.

Section 3.2.6 Miscellaneous Maintenance

1. Initially check tightness of guy wire turnbuckles. Tighten as required.
2. Check torque on rotor hub and bolts holding flexstrap to flexbeam every time turbine is lowered to ground level. Retorque as necessary.
3. Similarly check bolts holding blades on flexbeam.

SECTION 4

SYSTEM SERVICING

Section 4.1 WTG Removal

1. Remove the upper guy wire, facing the winch, from its ground anchor.
2. Attach a come-along to the thimble of this wire's turnbuckle and attach the other end to one of the two side holes in the jib boom's head fitting.
3. Pull the jib boom up to the turnbuckle with the come-along. Attach the turnbuckle clevis to the upper hole in the jib boom's head fitting with clevis pin. Secure with cotter pin.
4. Release tension from come-along and remove from guy wire.
5. Install snatch block in lower hole of jib boom's head fitting. Attach double sheave pulley to ground anchor.
6. Attach 1/2-in. cable between hand winch and jib boom. Take up cable slack with the winch. Select low speed on winch.
7. Use two 7/8-9 jacking screws in the tower base plate to initiate tower lean, alternately paying out cable at the winch while tilting the tower with the jacking screws.

The weight of the tower should be felt at the winch by the time the tower is tilted about 2-1/2°, requiring no further assistance from the jackscrews. Use the winch to lower the tower to working level. CAUTION — NEVER lower the tower with the winch in high speed as it will become increasingly difficult to hold the tower as the tilt angle is increased, resulting in a loss of control with possible system damage or injury. ALSO — someone should stand by at the hand brake of the winch to be prepared to hold the drum in the eventuality that the winch operator finds it difficult to regulate the rate of lowering.

8. Insert 7-1/2 ft tower support near upper flange and lower the tower until it rests securely on this prop. Keep some tension in the winch cable.

Section 4.2 Blade Removal

This is a two-person job. Tool #4 is required.

1. Set rotor disc brake.
2. At outer end of flexbeam (blade #1 or #2) remove three 3/4-9 bolts from bushings in flexbeam. The 2nd person should support the pendulum's pitch arm as the last bolt is removed. The flexstrap should be tied up out of the way using rope or wire.
3. Using tool #4, carefully press out each of the three,1-in. bushings which secure the aluminum yoke to the flexbeam.
4. Support the second blade near its tip to prevent the nacelle from swinging when the first blade is removed.
5. With one person at the blade's tip and a second at the root, gently rock the blade in a leading/trailing edge motion while exerting a radial force to pull the blade off the flexbeam.
6. Repeat the process on the remaining blade. CAUTION — It is highly advised that blade removal always be accomplished at ground level. However, should removal be required with the WTG installed, proceed as above, however, the two blades must be oriented horizontally and the blade with the leading edge DOWN must be removed first. This is to prevent the possibility of the rotor turning due to the removal of the first blade causing either property damage or personal injury. An anti-reversing clutch will prevent the BACKWARD rotation of the rotor during this operation.

Section 4.3 Rotor Head Removal

1. Remove WTG per Section 4.1.
2. Remove rotor blades per Section 4.2.
3. Remove aerodynamic fairing (nacelle) (Fig. 16) by:
   a. Releasing 12 snap fasteners securing the upper and lower section.
   b. Lift away the upper fairing.
   c. Release four snap fasteners securing the two lower sections.
   d. Remove two Allen screws from each of the four side brackets inside the fairing.
3. Pull two lower fairing halves apart and lift away.

4. Release disc brake.
5. Loosen four nuts on "U" bolts, holding cables inside tower. Remove long grease fitting near upper flange from yaw shaft.
6. Remove ten 7/8-9 hex head bolts that secure the upper two flanges together.
7. Attach lifting cables between the rotor head assembly and the overhead hoist.
8. Take up strain on hoist then remove the last two 7/8-9 bolts holding flanges together and slide out about 18 in. NOTE — as the head assembly is pulled out of the tower, a second person should be feeding the electrical and instrumentation cables into the tower at its base to prevent cables from binding up.
9. Continue to pull out the head assembly, while feeding both the power and instrumentation cables in at the tower's base.
10. Disconnect the instrumentation cables at the WK-5 connectors near the yaw shaft.
11. Disconnect the power cables at the screw-on terminals near the yaw shaft.
12. Leave instrumentation cables and power cable in tower for reassembly.

Section 4.4 Flexbeam Removal

1. Remove WTG per Section 4.1.
2. Remove both rotor blades per Section 4.2.
3. Turn off power to strain gages.
4. Disconnect Winchester instrumentation connector at the rotor hub.
5. Remove instrumentation cable clamp from hub surface. Tie up the instrumentation cable, coming off the flexbeam, to the flexbeam.
6. Sequentially loosen ten bolts holding hub halves together.
7. Remove two bolts holding the pitch arm to the hub. Remove crossarm, pitch arm, pendula,and flexstraps from the hub, as a unit.
8. Remove remaining eight bolts holding hub halves together. Remove front half of hub and the two side rail spacers.
9. Remove flexbeam.

Section 4.5 Rotor Hub Removal

1. Remove WTG per Section 4.1.
2. Remove both rotor blades per Section 4.2.
3. Remove flexbeam per Section 4.4.
4. Remove six 1/2-13 hex head bolts from the back side of the hub.
5. Gently tap hub plate off the drive shaft using a fiber mallet.
6. Lift hub plate away, being careful with instrumentation lines coming through the hub's center.

Section 4.6 Generator Removal

1. Remove WTG per Section 4.1.
2. Remove rotor blades per Section 4.2.
3. Remove rotor head assembly per Section 4.3.
4. Disconnect three power lines at generator junction box.
5. Disconnect copper grease line from forward and rear motor flanges.
6. Disconnect generator tachometer signal wire at the magnetic pickup.
7. Thread lifting eyebolt into tapped hole on generator's upper surface.
8. Attach overhead hoist to eyebolt.
9. Remove 6 1/2-13 hex head bolts from gearbox output flange.
10. Slide generator away from gearbox, until the turret coupling between the generator and gearbox disengages. Some rocking of the generator may be required to accomplish this.

Section 4.7 Gearbox Removal

1. Remove WTG per Section 4.1.
2. Remove both rotor blades per Section 4.2.
3. Remove rotor head assembly per Section 4.3.
4. Remove electric generator per Section 4.6.
5. Remove six 1/2-13 hex head through-bolts from low-speed FMC coupling.
6. Separate the two halves of the low-speed coupling.
7. Remove four 7/8-14 elastomer nuts holding the gearbox to the base plate.
8. Secure gearbox to overhead hoist with nylon straps across the input and output shafts.
9. Lift gearbox up and away from the main frame.

SECTION 5

TROUBLESHOOTING

1. Rotor Blades Do Not Turn
    a. Insufficient wind
    b. Rotor facing backward into wind; wait for rotor to yaw
    c. Disc brake dragging
    d. Misalignment of drive shaft and gearbox causing shaft binding
    e. Failure of either of two drive shaft bearings
    f. Failure within gearbox
    g. Bearing failure in generator
2. Rotor Blades Turn But Very Slowly
    a. Insufficient wind
    b. Rotor not aligned in downstream position; wait for yaw
    c. Unusually high friction in drive system (see 1b-1f)
    d. Incorrect pendulum setting
    e. Pendulum pitch arm binding (blade angle not varying with rpm)
    f. Improper gearbox lubricant
3. Rotor Blades Turn at High rpm But No Power Out
    a. One of three switches on electrical controls is open
    b. Blown fuse in fuse box
    c. Power grid is down
    d. Defective relay R1
    e. Speed switch not closing at preset rpm
    f. Brushes on power slip rings damaged or worn
    g. Defective generator
    h. Broken coupling between generator and gearbox
4. Rotor Continues to Turn in Still Air (Motoring of Generator)
    a. Defective relay R1
    b. Speed switch not opening at preset rpm
5. Unusual Vibration or Noise/1-Rev
    a. Two blades not statically balanced
    b. Blade angles-of-attack differ; pendulum dissimilarity
    c. Crack or defect on one blade
    d. Main rotor bearing, shaft or coupling damaged or out of alignment

6. Rotor Cannot Be Stopped with Disc Brake
   - a. Wind speed too high
   - b. Worn brake pads
   - c. 12-volt battery discharged
   - d. Defective brake actuator
   - e. Blown fuse in battery circuit
   - f. Clutch slip on actuator set at too low a limit
   - g. Brake needs bleeding
   - h. Master cylinder defective
   - i. Loss of brake fluid
7. Rotor Does Not Track Wind Direction Changes
   - a. Defective yaw bearing(s)
   - b. Fused power brushes on slip ring
8. Rotor Turns Backwards
   - a. Defective backstop in gearbox
   - b. Defective flexible coupling on low speed shaft
   - c. Rotor hub is loose on shaft

SECTION 6

TORQUE VALVES

Location	Bolt Size	Recommended Torque lb-ft
Tower		
Base retainer	2(2) 1 1/4-7	200
Mid tower flange	(12) 7/8-9	150
Upper intermediate flange to tangs	(6) 7/8-9	150
Rotor head assembly flange to upper tower flange	(12) 7/8-9	150
Head Assembly		
Motor/gearbox flange	(6) 1/2-13	35
Gearbox/frame	(4) 7/8-14	150
FMC flexible coupling halves	(10)	110
Disc brake caliper to frame	(4) 1/2-13	35
Disc brake rotor to shaft	(5) 1/2-13	35
Rear drive shaft bearing retainer	(6) 1/2-20	35
Master cylinder to frame	(2) 3/8-16	20
Electric disc brake actuator to frame	(1) 1/2-13	35
Bellcrank to frame	(1) 1/2-13	35
Frame to yaw shaft	(4) 3/4-10	100
Front bearing retainer	(6) 1/2-20	35
Ringfeeder housing to hub	(6) 1/2-13	35

Rotor hub halves	(10) 3/4-16	100
Pitch arm plates to arm	2 (2) 5/8-18	75
Pitch arm oilite bearings	2 (1) 1-14	75
Pendulum weight retainers	2 (2) 1 1/4-7	75
Bracket to flexbeam	2 (6) 3/4-10	100
Flexstrap to bracket	2 (5) 1/2-20	50
Nacelle (lower) to frame	(7) 1/4-28	15

SUMMARY

Rated power	8 kW
Rated wind speed	20 mph
Rotor speed	106-112 rpm (175 fps)
No. of blades	2
Diameter	31 ft
Chord	15 in.
Airfoil series	23112
Taper	None
Twist	0°
Start-up blade angle	16°
Operating blade angle	0°
Pre-cone	8°
Generator rating	15 kW
Synchronous speed	1800 rpm
Gear-reducer ratio	17/1
Tower height	55 ft

7.8 GLOSSARY

ANEMOMETER - A device to measure wind speed.

ANEMOMETER DISTANCE CONSTANT - A measure of the frequency response characteristics of an anemometer, which is determined by the length of wind run that must pass an anemometer before it indicates 63% of the actual amplitude of a step-change gust.

ATMOSPHERIC TEST - The conduct of SWECS testing under natural wind conditions.

BIN WIDTH - The size of the wind speed interval (expressed in mph per hour) used in the method-of-bins data analysis technique.

CYLINDER OF PROJECTION OF SWECS ROTOR - The cylinder whose axis is aligned with the wind direction and passes through the center of the rotor, whose cross-section extends 3 rotor diameters upwind of the rotor and 6 rotor diameters downwind of the rotor.

DISCONNECT - a device or group of devices or other means by which the conductor of a circuit can be disconnected from the source of electrical supply.

ELECTRICAL GROUND - A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth.

ELECTRICAL LOAD - An electrical device that uses electrical energy.

ELECTRICAL UTILITY/USER INTERCONNECTION - The physical connection of the electrical hardware of the SWECS to the electrical systems of both the utility and the user.

FREE STREAM AREA - That area in a wind tunnel test section which the wind speed in the absence of an obstruction is uniform within ± 5%.

HORIZONTAL AXIS WIND TURBINE - A SWECS that has an axis of rotation of the rotor nominally in a horizontal plane.

INTERCONNECTED SWECS - A SWECS that is electrically connected to the utility system and could feed power back into the utility system.

INTERTIE - The interconnection of an electrical generating device; e.g., a wind turbine, with a utility grid.

MAXIMUM DESIGN SWECS POWER OUTPUT - As specified by the SWECS manufacturer, the maximum power output expected from the SWECS when it is operating within its design operating conditions.

METHOD-OF-BINS - A data analysis technique consistingof partitioning the wind speeds observed into a selected number of equally spaced intervals or bins. The average of all SWECS power output values observed, essentially simultaneously with a wind speed value in a given bin, is the power associated with the wind speed at the center of the bin.

NORMAL SOIL - A cohesive soil with an allowable net vertical bearing capacity of 4,000 lb/ft^2 and an allowable net horizontal pressure of 400 lb/ft^2 per lineal foot of depth to a maximum of 4,000 lb/ft^2. Rock, noncohesive soil, and saturated or submerged soil are not normal soil.

POWER CONDITIONING EQUIPMENT - A subsystem of the SWECS used to accomplish electrical compatibility between the wind turbine generator's power output and an electrical load.

POWER AND POWER OUTPUT - Electrical output of the SWECS as represented by the product of the in-phase voltage and current components, expressed in kilowatts.

POWER OUTPUT CURVE - A graphical plot of SWECS power output (in kilowatts) versus wind speed (mph).

PROJECTED FRONTAL AREA - The profile area of an object as seen from the direction of the wind velocity.

RAYLEIGH DISTRIBUTION - An assumed wind speed distribution function which is used for wind energy conversion calculations. The distribution function, based on specified annual average wind speed, is defined by the following equation:

$$F(V) = V \left(\frac{\pi}{2}\right) \left(\frac{V}{\bar{V}^2}\right) \cdot \exp \left[-\frac{\pi}{4} \left(\frac{V}{\bar{V}}\right)^2 \right]$$

Where:

$F(V)$ = Frequency of occurrence associated with each incremental wind speed of ΔV centered at V. NOTE: The distribution function is equal to 8760 (F(V)).

V = The center of the wind speed increment (meters per second/miles per hour).

$\bar{V}$ = Annual average wind speed (meters per second/miles per hour).

ΔV = Width of the wind speed increment (meters per second/miles per hour).

RATED OUTPUT - The power output obtained from a SWECS operating at a given wind speed designated by the SWECS manufacturer.

ROTOR - A system of rotating elements that convert the energy in the wind into mechanical shaft power.

ROTOR-SWEPT AREA - The area as seen from the direction of the wind that a rotor would pass over during one revolution.

SMALL WIND ENERGY CONVERSION SYSTEM (SWECS) - An electrical wind energy device having a rated output of less than 100 kW, which may consist of such subsystems as wind turbine generator, a tower and/or structural support equipment, power conditioning equipment, and, in the case of interconnected SWECS, interconnect equipment.

SWECS CUTOUT SPEED -Wind speed above which the SWECS will no longer produce power under normal operating conditions.

SWECS MANUFACTURER - The manufacturer of the wind turbine generator subsystem of a SWECS.

SWECS MODEL - A SWECS with a specific hardware configuration established by the SWECS manufacturer for fabrication and sale to the general public.

STANDARD FOUNDATIONS AND ANCHORS - Structures designed to support the maximum combined dead and live loading expected for normal soil conditions. Pile construction, roof installation, foundations, or anchors designed for inundated soil conditions, etc., are not standard foundations and anchors.

STANDARD MEAN POWER OUTPUT - a theoretical representation of the power output (in kilowatts) produced by SWECS based on the following:

(i) Power output curve of the SWECS.

(ii) Wind speed characteristics derived from a Rayleigh Distribution at the designated average annual wind speed.

STANDARD OPERATING TIME FACTOR - The percentage of the total possible operating time a wind energy conversion system would be producing power based on the following:

(i) The power output curve of the system.

(ii) Wind speed characteristics derived from a Rayleigh Distribution at a designated average annual wind speed.

SURVIVAL WIND SPEED - The maximum wind speed, as designated by the SWECS manufacturer, at which a SWECS, in unattended operation (not necessarily producing power), is designed to survive without damage to structural components or loss of the ability to function normally.

TOWER - A subsystem of a SWECS that supports the wind turbine generator.

TOWING TEST - The conduct of SWECS testing where the SWECS is mounted on a moving vehicle (such as a truck or train flat car).

VERTICAL AXIS WIND TURBINE - A SWECS that has an axis of rotation of its rotor perpendicular to the horizontal plane of the ground.

WIND TUNNEL TEST - A SWECS test in artificial wind when the SWECS is mounted in a structure designed to control the wind characteristics during the test.

WIND TURBINE GENERATOR - That portion of the SWECS that converts wind energy into electric power, including components such as the rotor, generator, and control equipment.

YAW - means the rotation of a horizontal axis wind turbine about its yaw axis.

YAW AXIS - The axis about which the directional orientation of a horizontal axis wind turbine is changed.

7.9 REVIEW QUESTIONS

1. The only acceptable method under RCS for testing performance data of SWECS (Small Wind Energy Conversion Systems) is:

   a. Atmospheric
   b. Wind tunnel
   c. Towing
   d. Theoretical

2. The methods allowable for testing for modifications to SWECS are:

   a. Atmospheric
   b. Wind tunnel
   c. Towing
   d. Theoretical

3. All reported test data involving SWECS power output will be corrected to a standard air density of 1.2 kg/m^3 using:

$$PS = \frac{1.2}{DM} PM$$

where:

PS =power output (kilowatts) corrected to a standard air density of 1.2 kilograms per cubic meter.

PM =measured power output (kilowatts).

DM =air density (kilograms per cubic meter) at the test site.

Given PM = 2.0 kw and DM = 1.0 kg/m^3, what is PS?

   a. 24.0 kW
   b. 2.4 kW
   c. 0.6 kW

4. Reference wind data must be corrected to the center of the SWECS motor height using the 1/7th power law. The purpose of this is to:

   a. Increase the wind speed at the rotor height
   b. Decrease the wind speed at the rotor height
   c. Determine the wind speed at the rotor height

5. The responsibility for providing the standard foundations and anchor design of the SWECS lies with:

   a. Dealer
   b. Installer
   c. Utility
   d. Customer
   e. Manufacturer

6. The responsibility of providing a detailed parts list, instructions for assembly installation, and checkout lies with:

   a. Dealer
   b. Installers
   c. Utility
   d. Manufacturers

7. When an installation requires a deviation from the method proposed by the manufacturers, the installer must get written concurrence from:

   a. The utility
   b. The manufacturers or representative

8. The responsiblilty for SWECS operation without damage to the intertie components in the case of utility line de-energization is with:

   a. The utility
   b. The manufacturer
   c. The user

9. The interconnection of a wind energy device under RCS must be made on which side of the utility revenue meter?

   a. Utility side
   b. User side

10. In order to assure safety to utility linemen, which safety device is required with a SWECS installation under RCS?

    a. Lockable disconnect switch
    b. Circuit breaker
    c. Fuse
    d. Controller safety switch

11. Electrical power instrumentation used in testing SWECS for RCS should measure:

    a. Power produced by the SWECS
    b. Power delivered by the SWECS minus power consumed by the control subsystems and power conditioning equipment

12. All SWECS electrical equipment and methods of interconnection must be installed to conform to:

    a. Manufacturer's specifications
    b. NEC
    c. NEC as augmented by local codes
    d. Dealer written instructions

13. Does RCS require a hazard warning label on the SWECS housing?

    a. Yes
    b. No

14. Does RCS require an information label on the SWECS housing?

    a. Yes
    b. No

15. Does RCS require a power conditioning label listing maximum power input, rated voltage, and current on the SWECS power conditioning unit?

    a. Yes
    b. No

16. Can an installer put up a taller tower than the one specified by the manufacturer if the customer demands it?

    a. Yes
    b. No

17. A SWECS can be allowed to yaw and extend over the neighbor's property because it is a "temporary situation".

    a. Yes
    b. No

18. Guy-wire connections can be put at any point on the tower that the installer can most directly access.

    a. Yes
    b. No

19. SWECS installations are immune from local codes because they are energy producers.

    a. Yes
    b. No

20. An anemometer measures:

    a. Electrical power
    b. Wind speed or wind run
    c. Solar insolation

CHAPTER 8

HUD — MINIMUM PROPERTY STANDARDS

This document presently addresses active solar system standards. It can be ordered from the U.S. Government Printing Office. All recipients of this workbook are encouraged to purchase and insert this document into their workbook.

GOVERNMENT PRINTING OFFICE
ORDER FORM

To order the **HUD Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems (Vol. 5)** fill out the following order form and return with check or money order, or credit card number to:

Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402

Quantity	Stock No.	Title	Unit Price	Total Price
	023-000-81007-7	HUD Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems	$12.00	

Name: ____________________

Company Name: ____________________

Street Address: ____________________

City ____________ State ____________ ZIP Code ________

Enclosed is $ ____________

Check or money order made payable to Superintendent of Documents.

Please do not send cash or stamps

Credit Card Orders only:

Total charge $ ____________

Credit Card No. ____________

Check one:

VISA ________ Master Charge ________

Expiration Date: ____________

CHAPTER 9

HUD — INSTALLATION GUIDELINES

This document presently addresses active solar system standards. It can be ordered from the U.S. Government Printing Office. All recipients of this workbook are encouraged to purchase and insert this document into their workbook.

GOVERNMENT PRINTING OFFICE
ORDER FORM

To order the **Installation Guidelines for Solar Domestic Hot Water Systems** fill out the following order form and return with check or money order, or credit card number to:

Superintendent of Documents
U.S. Government Printing Office
Washington D.C. 20402

Quantity	Stock No.	Title	Unit Price	Total Price
	023-000-00520-4	Installation Guidelines for Solar DHW Systems	$4.25	

Name: ______________________________

Company Name: ______________________________

Street Address: ______________________________

City ______________ State ______________ ZIP Code __________

Enclosed is $ ______________

Check or money order made payable

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Please do not send cash or stamps

Credit Card Orders only:

Total charge $ ______________

Credit Card No. ______________

Check one:

VISA ________ Master Charge ________

Expiration Date: ______________

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CONSERVATION

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"Installation of Oil Burning Equipment". NFPA 31-1978. $5.50.

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"Standard Method of Test for Smoke Density in the Flue Gases from Distillate Fuels". ANSI/ASTM D2156-65 (1975). $4.00.

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"Standard Practice for the Installation of Storm Windows, Replacement Windows, Multi-Glazing, Storm and Replacement Doors". ASTM E737-80. $4.00.

"Standard Recommended Practice for Selection of Vapor Barriers for Thermal Insulation". ASTM C755-73. $4.00.

"Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C". ASTM 136-79. $4.00.

"Standard Test Method for Surface Burning Characteristics of Building Materials". ASTM E84-79b. $4.00.

Status of Thermal Imaging Technology As Applied to Conservation. Department of Energy. December 1978. NTIS number HCP/M 4228-01. UC-95d. $6.50.

Documents listed above are available from the following sources. Refer to document order number for appropriate mailing address.

ANSI

The American National Standards Institute
1430 Broadway
New York, New York 10018
(212) 354-3300
(Attention: Sales Department)

ASTM
The American Society for Testing and Materials
1916 Race Street
Philadelphia, Pennsylvania 19103
(215) 299-5400
(Attention: Maureen Freec)

FGMA
Flat Glass Marketing Association
White Lake Professional Building
3310 Harrison
Topeka, KS 66611

GPO
Government Printing Office
Superintendent of Documents
Washington, D.C. 20402

NTIS
National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
(703) 737-4650

RENEWABLE RESOURCES

Active Solar Energy System Design Practice Manual, DOE National Solar Program. 1979. Available NTIS. $14.00.

ASHRAE Handbook and Product Directory: 1977 Fundamentals—Section 4. Load Calculations. 1977. ASHRAE.

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CONSTRUCTION

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From the Walls In, Charles Wing, 1979. Atlantic Monthly Press, Little Brown and Co. Boston, MA 02106. $9.95.

Wood Frame House Construction, USDA-Agriculture Handbook, No. 73. 1975. $3.40.

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Superintendent of Documents
Washington, DC 20402

NTIS
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Rd.
Springfield, VA 22161
(703) 737-4650

SERI
Solar Energy Research Institute
Document Distribution Service
1617 Cole Boulevard
Golden, CO 80401
(303) 231-1158

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APPENDIX A.1

FEDERAL REGISTER (EXCERPT)

Federal Register/Vol. 45. No. 187/Wednesday, September 24, 1980/
Rules and Regulations 63443

Section 456.314 Qualification Procedures for Auditors, Installers and Inspectors.

(a) Auditor qualification requirements.

(b) Installers and inspectors of automatic vent dampers and automatic intermittent pilot ignition devices (IID's) for gas-fired central furnaces and low-pressure hot water boilers.

(c) Installers and inspectors of wind energy devices.

(1) The State Plans shall contain procedures to assure that any person or persons installing a wind energy device under the circumstances described in the State Plan pursuant to § 456.305 and any person or persons conducting a post-installation inspection of wind energy device pursuant to § 458.313(a) shall have the following qualifications:

(i) Familiarity with the installation standards for wind energy devices in Subpart G;

(ii) Familiarity with the structural characteristics of wind energy devices;

(iii) Familiarity with national and local codes governing the electrical interconnection between the wind energy device and the residential and/or utility electrical system; and

(iv) A general knowledge of the test procedures described in § 456.705.

(2) The State Plan shall contain procedures to assure that any person or persons installing a wind energy device under the circumstances described in the State Plan pursuant to § 458.305 shall demonstrate proficiency in the installation of wind energy devices, and familiarity with the testing of wind energy devices in accordance with the procedures described in § 458.705.

(d) Installers and inspectors of solar domestic hot water systems, active solar space heating systems, and combined active solar space heating and solar domestic hot water systems.

(1) The State Plan shall contain procedures to assure that any person or persons installing a solar domestic hot water system, an active solar space heating system, or a combination thereof, under the circumstances described in the State Plan pursuant to § 458.305, and any person inspecting such systems pursuant to § 456.313(a), shall individually or collectively be knowledgeable about:

(i) The residential construction methods employed in the region and the characteristics of structures that would preclude a safe and enduring solar installation;

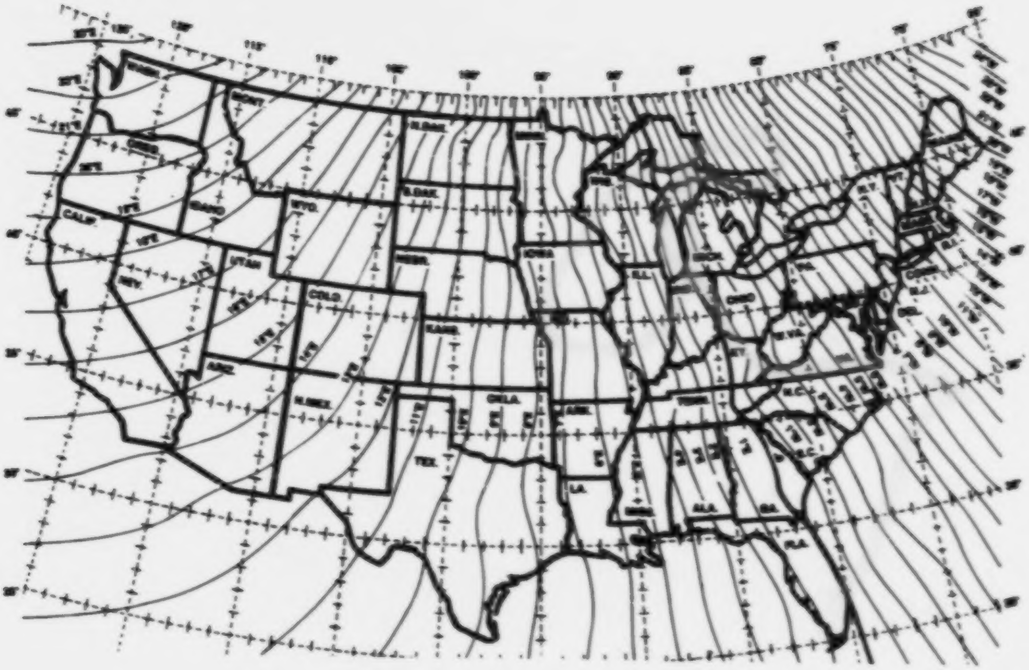
(ii) The applicable provisions of the HUD Intermediate Minimum Property Standards Supplement, as required in Subpart G;

(iii) The design, operation, installation and degradation of residential hot water and heating systems with which the solar devices will interconnect; and

(iv) The connection of the solar devices into the existing residential systems, including testing for satisfactory performance of the solar devices and the modified system, according to the requirements of the HUD Intermediate Minimum Property Standards Supplement as required for the program in Subpart G.

(2) The State Plan shall contain procedures to assure that any person or persons installing a solar domestic hot water system, an active solar space heating system, or a combination thereof under the circumstances described in State Plan pursuant to § 456.305, shall demonstrate proficiency in the connection of the solar devices into existing residential systems, in conformance with the applicable provisions of the HUD Intermediate Minimum Property Standards Supplement, as required for the program in Subpart G.

APPENDIX A.2

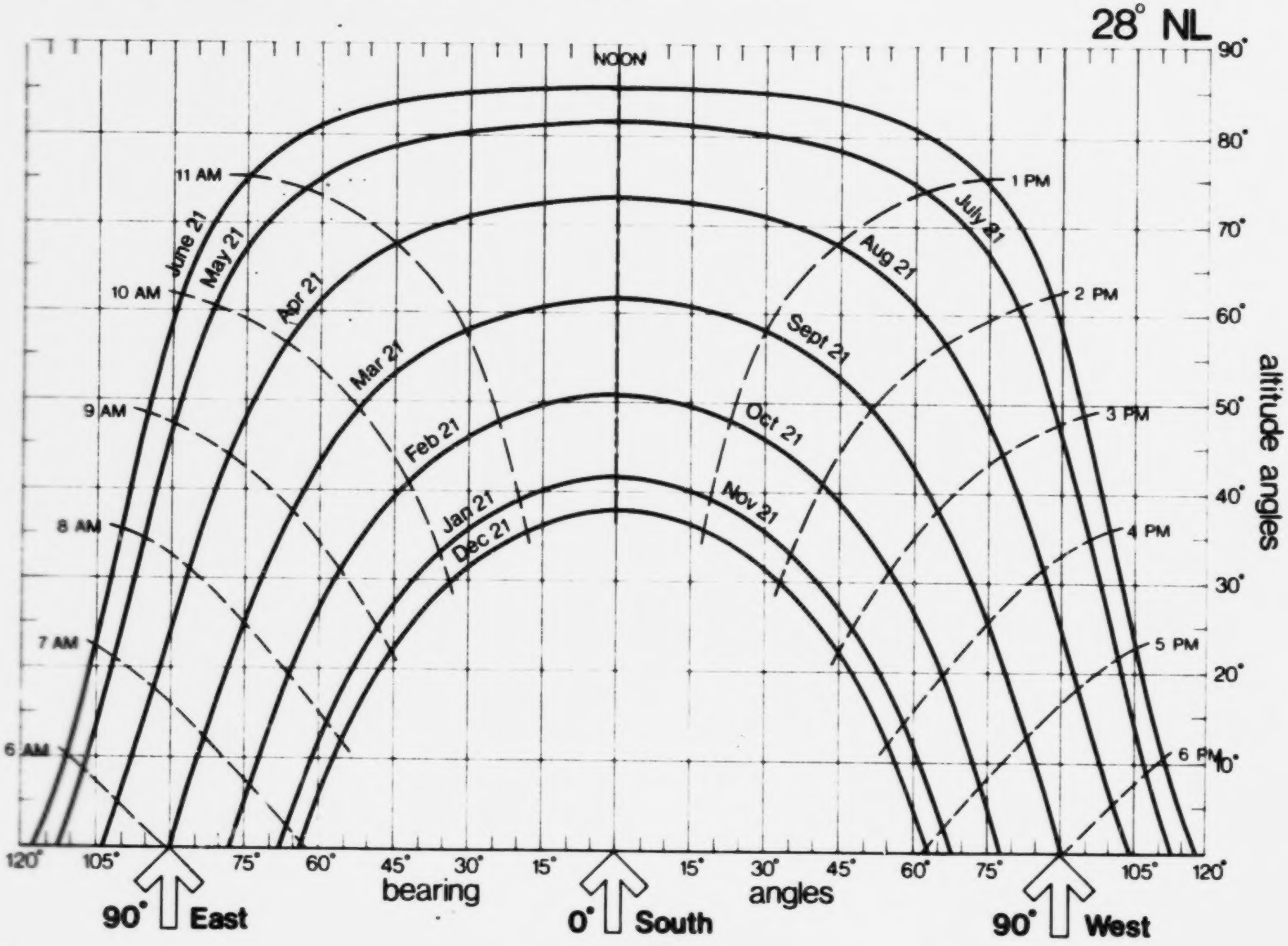


Isogonic Chart of the United States

Due to the earth's magnetic field, it is necessary to adjust the compass reading by a few degrees east or west to obtain true north (different from magnetic north) for your area. This adjustment is the isogonic correction. To use the chart, locate your area on the map and determine the appropriate easterly or westerly magnetic deviation for your location. The number corresponding to the line is the number of degrees from true north that your compass will read. For example, if the number is 13° E, your compass will read 13° E of true north.

Sun Charts

The following sun charts are for all latitudes from 28° to 56°NL at 4° intervals.



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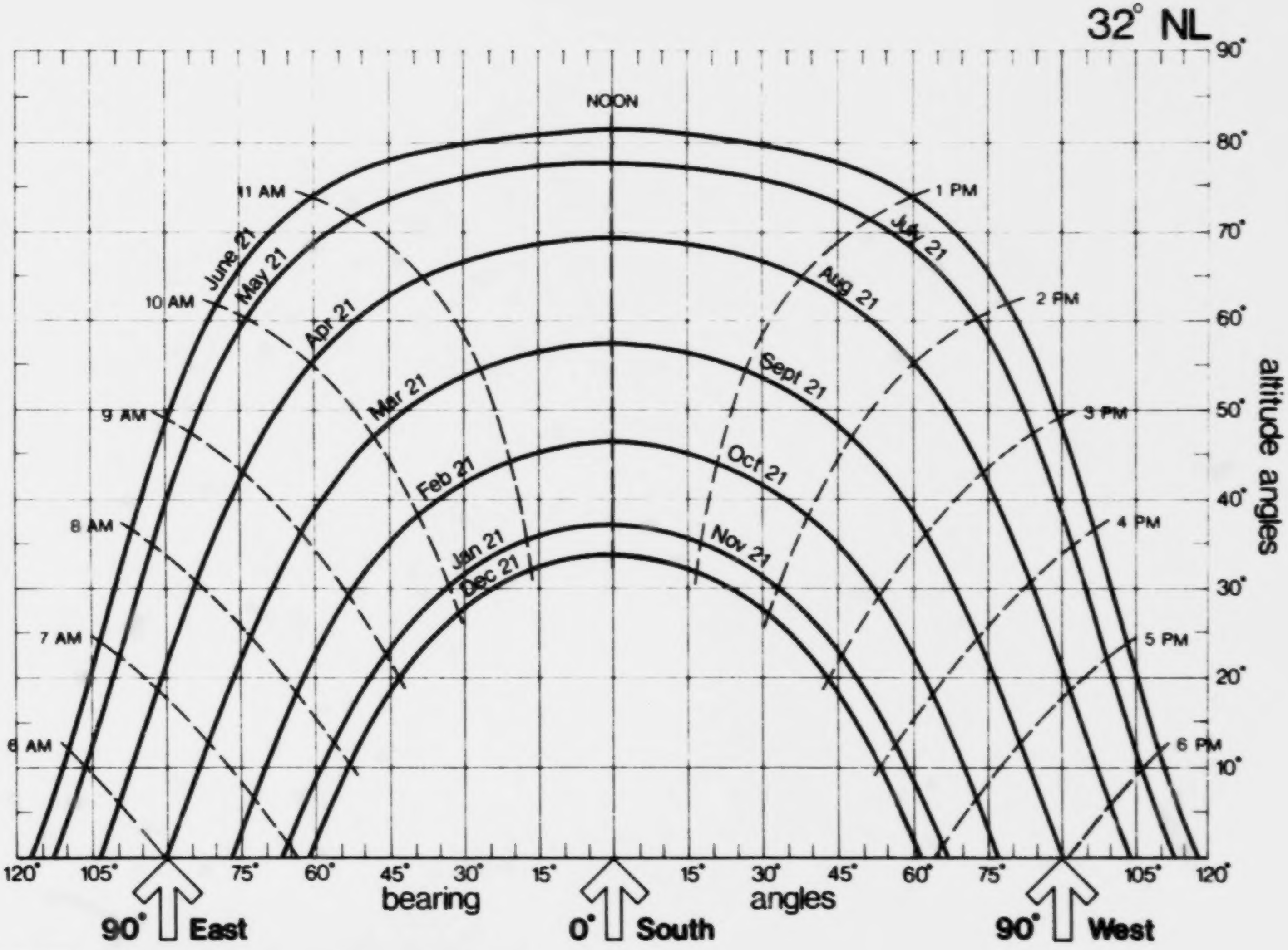

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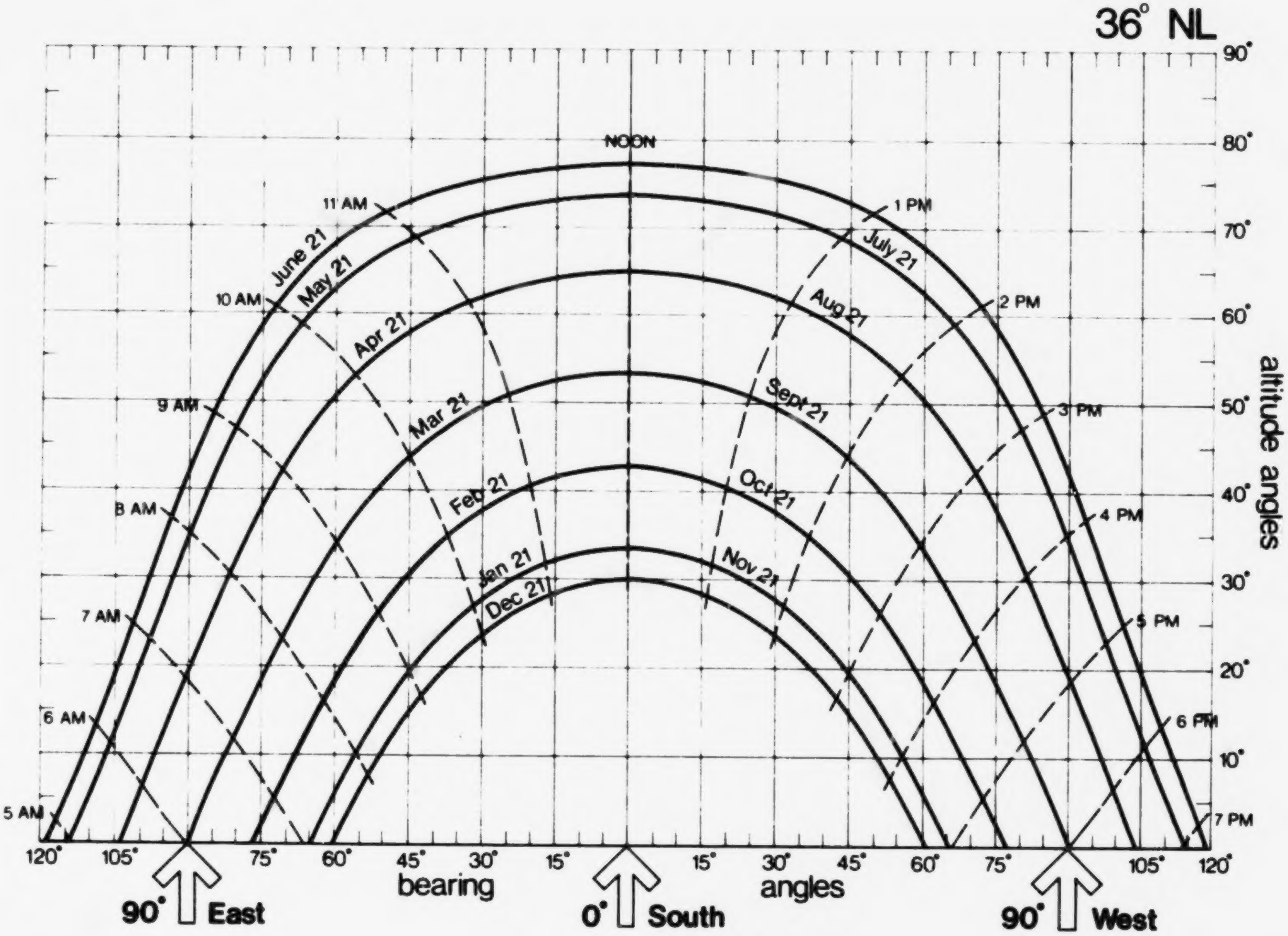
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NOON
11 AM
10 AM
9 AM
8 AM
7 AM
6 AM
5 AM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7 PM
June 21
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Dec 21
July 21
Aug 21
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Nov 21
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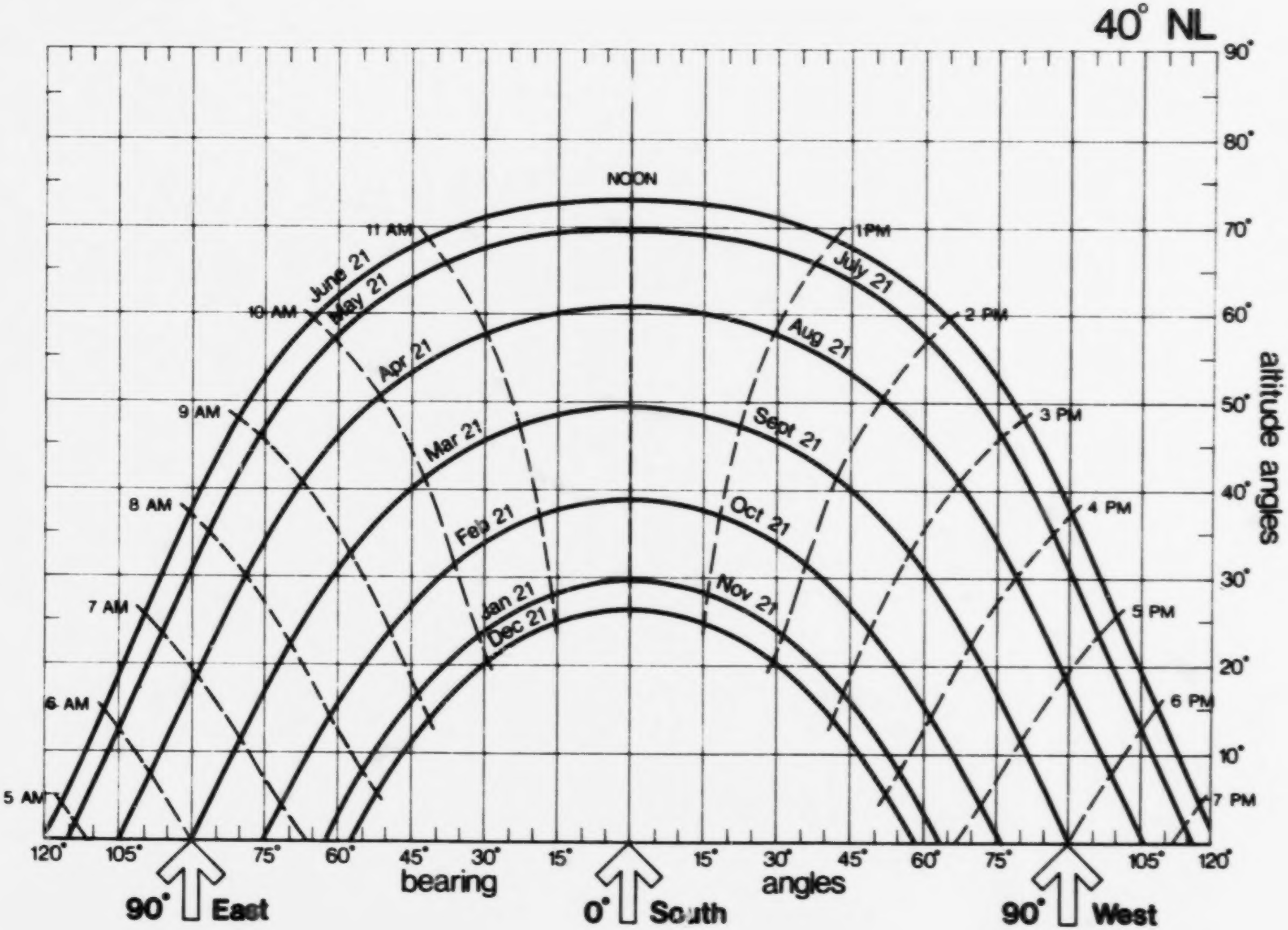

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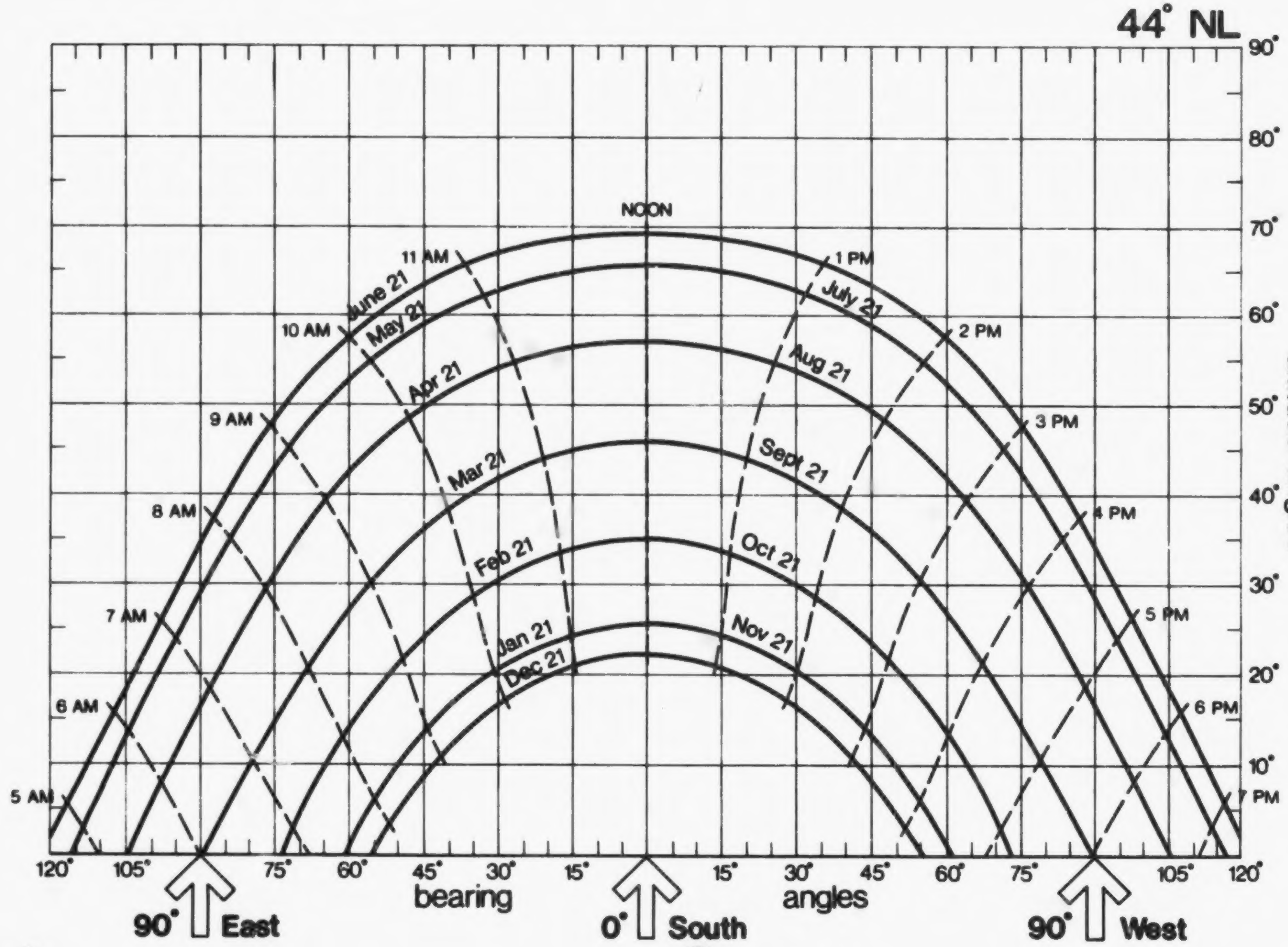
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Mar 21
Feb 21
Jan 21
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July 21
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Oct 21
Nov 21
90°
80°
70°
60°
50°
40°
30°
20°
10°
altitude angles
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105°
75°
60°
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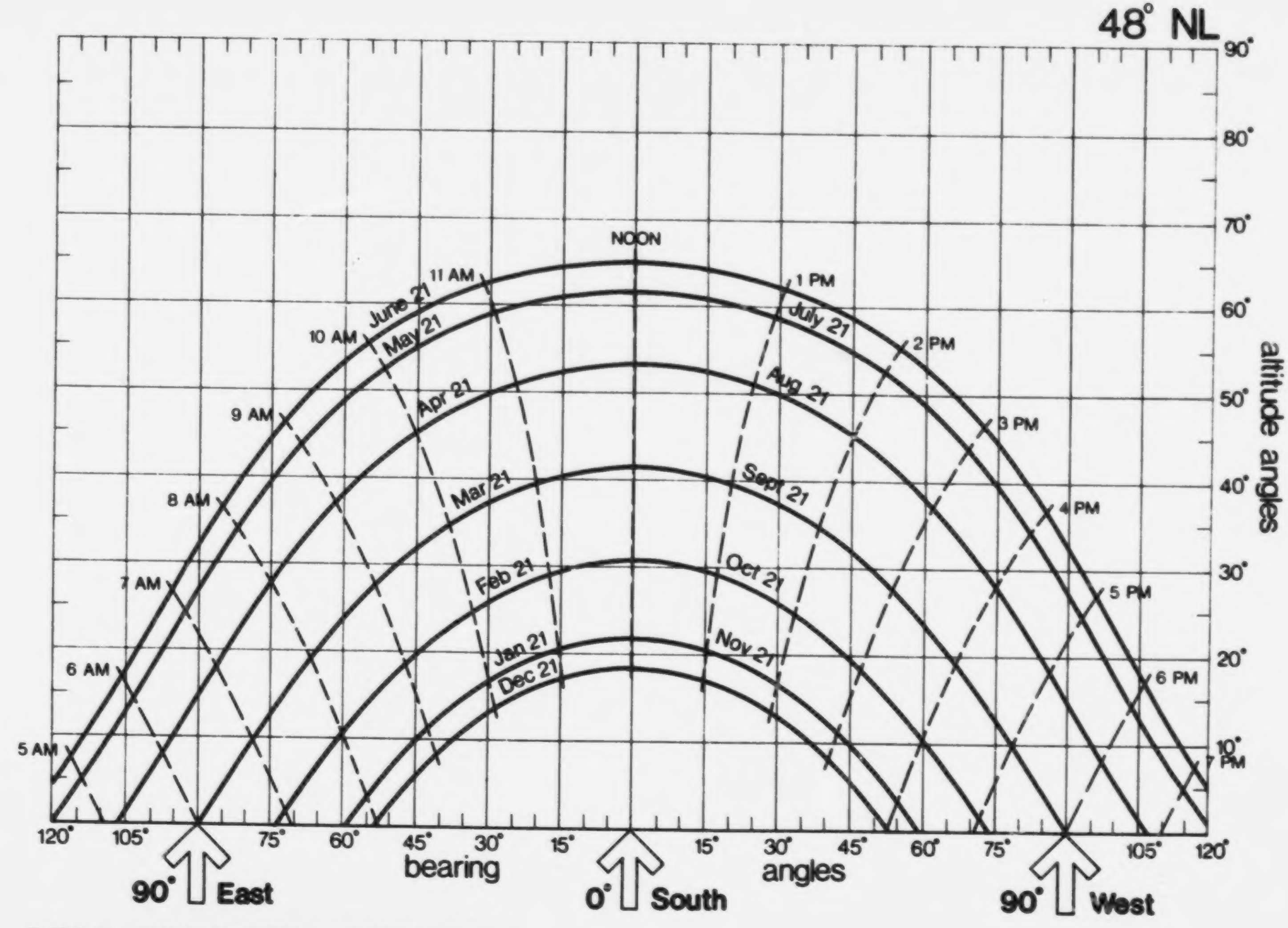
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Dec 21
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Sept 21
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Nov 21
90°
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20°
10°
altitude angles
120°
105°
75°
60°
45°
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90° West

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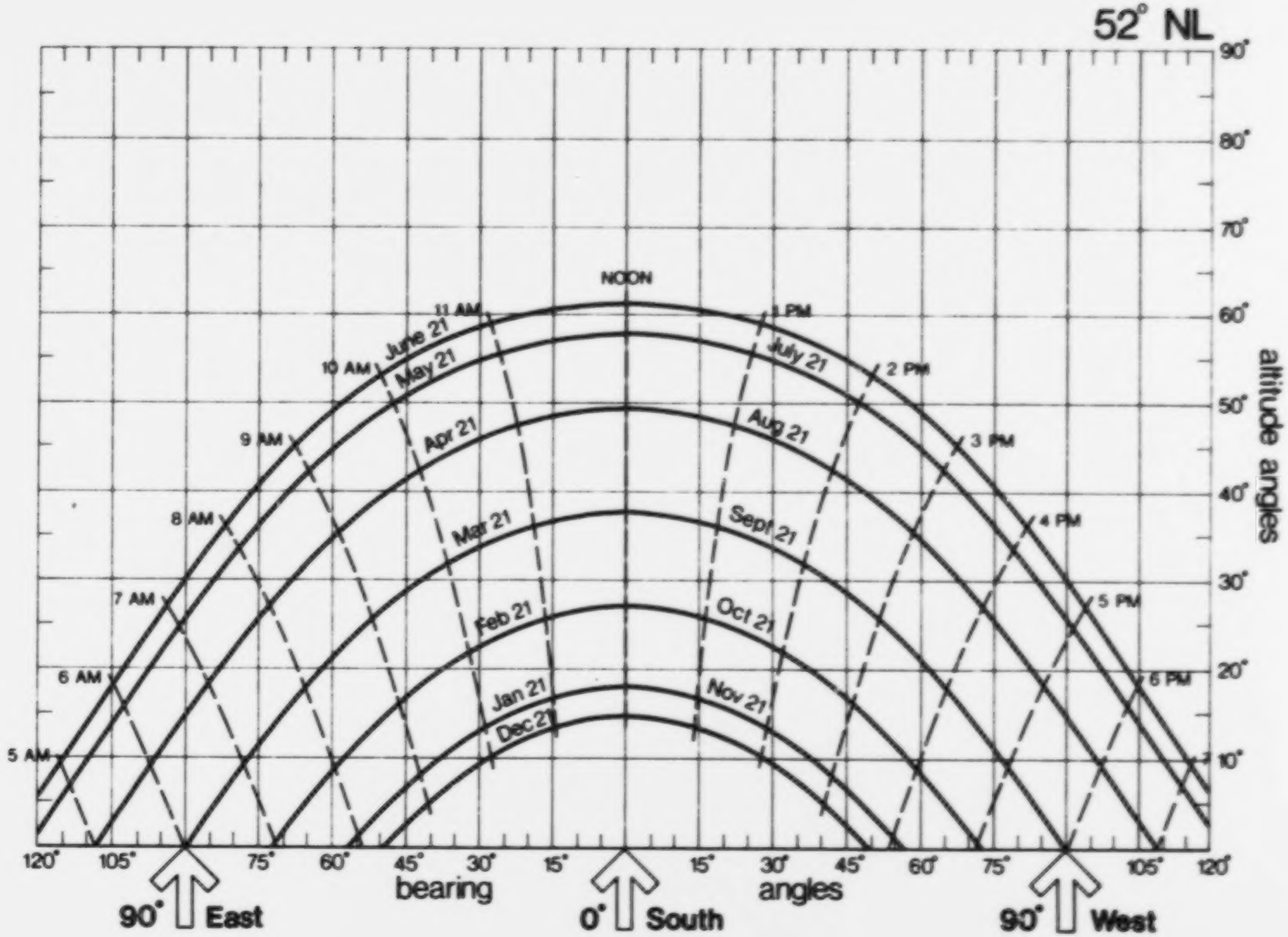
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20°
10°
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7 AM
6 AM
5 AM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7
June 21
May 21
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Dec 21
July 21
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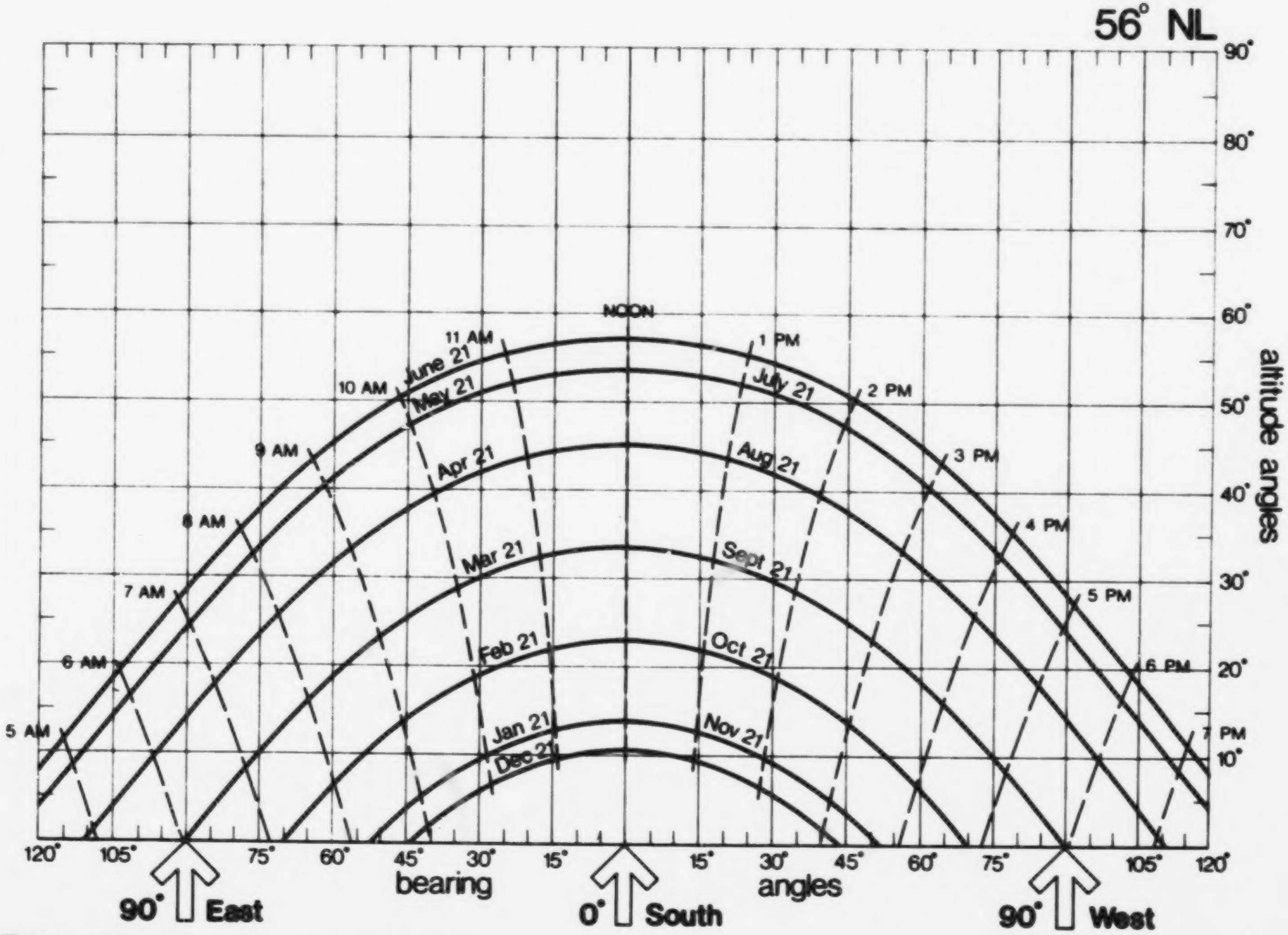
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1 PM
2 PM
3 PM
4 PM
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6 PM
7 PM
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
120°
105°
75°
60°
45°
30°
15°
15°
30°
45°
60°
75°
105°
120°
bearing
angles
90° East
0° South
90° West

SP-1130

APPENDIX A.4

DEVICES FOR SOLAR ACCESS MEASUREMENT

Solar Pathfinder$^{\text{tm}}$
Solar Pathways, Inc.
Valley Commercial Plaza
3710 Highway 82
Glenwood Springs, CO 81601

Price: $144.00
(303) 945-6503

The reflected image of all shadow-casting objects is displayed on the surface of a transparent, reflecting dome. The sunpath diagram beneath the dome assigns solar-time and energy values to each obstruction. The full year's data is contained in a single image. Diagrams cover 5° latitude bands.

Sunbloc$^{\text{tm}}$
Pacific Sun, Inc.
437 Tasso St.
Palo Alto, CA 94301

Price $125.00
(415) 328-4588

A Brunton handheld transit is supplied to enable the angle of elevation of each shading object to be observed. Sequential readings at various azimuth angles enable measurements of all shadow patterns.

Solar Site Selector
Lewis and Associates
105 Rockwood Drive
Grass Valley, CA 95945

Price: $79.50
+ $8.00 (summer grid)
(916) 272-2077

Sunpaths are printed on transparent grids. Sighting through a "distortion optic" enables coincident viewing of shading objects and sunpaths. Sighting grids cover 2° latitude bands.

Sun Angle Calculator$^{\text{tm}}$
Zomeworks
P.O. Box 712
Albuquerque, NM 87103

Price: $75.00
+ $5.00 postage/handling
(505) 242-5354

Shading objects and transparent sunpath grid are coincidentally lighted in a plane mirror, horizontally mounted at the center of the instrument. Successive sightings at various azimuth angles enable construction of a "horizon plat".

APPENDIX A.5

ASHRAE STANDARD 93-77 (ABSTRACT)

The ASHRAE Standard 93-77 details the universally accepted procedure for thermal performance testing of solar collectors. Provisions are included for the testing of both flat plate and concentrating solar collectors. In addition to specific test procedures, ASHRAE 93-77 sets standards for all scientific test equipment used, as well as minimum climatic conditions required for the outdoor testing of solar collectors.

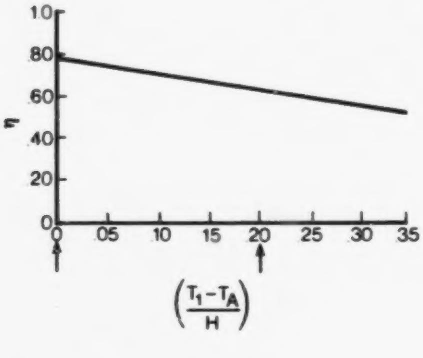
It is important to note that ASHRAE Standard 93-77 is a test procedure and not a minimum performance specification or quality standard.

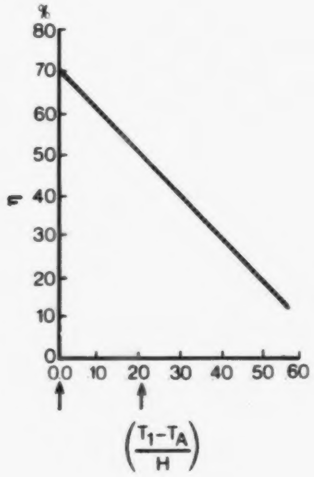
The ASHRAE Standard 93-77 test consists of:

- Three days of preconditioning by exposure to the sun while in a dry condition, i.e., drained of any liquid.
- Instrumented testing of the collector performance for short periods while exposed to actual or simulated sunshine.
- Presentation of test data in both tabular form and as a graph (i.e., curve).

HUD/MPS imposes an additional requirement that the ASHRAE 93-77 test procedure be repeated on the same dry collector after 30 days of exposure to sunshine and elements including rain. Comparison of thermal performance data on the initial test with thermal performance data after the 30-day exposure test must agree within 10%. In addition, no degradation of collector materials, particularly the glazing and absorber, can be evident.

Thermal performance test results are expressed in terms of collector efficiency. The concept of collector efficiency is best illustrated by what is known as the collector efficiency curve. The efficiency, (η) of a particular collector is expressed as a function of the temperature of the fluid entering the collector (T_1), the ambient temperature (T_A), and incident solar flux (H). The following efficiency curves illustrate the relationship between these variables.





In general these graphs show what percentage of available solar energy received by the collector is converted to useful energy for heating water, depending on the operating temperatures and solar irradiation (available solar energy). It is important to compare the efficiencies of collectors for only the range of operating temperatures, not over the complete range of temperatures (the complete range is shown along the horizontal axis of the graphs, also called the horizontal parameter). For example, during the summer the outside air temperature may be 100°F, the collector inlet fluid temperature 115°F, and the solar radiation 300 Btu/h/ft^2. Then the horizontal parameter $(T_1 - T_A)/H = (115 - 100)/300 = .05$ (note arrows on graphs). According to the graphs, under these conditions the collector on the left would convert about 65% of the available solar energy and the collector on the right about 75%. However, during the winter the outside temperature could be 55°F, the collector inlet fluid temperature 100°F, and the available solar energy 250 Btu/h/ft^2. In this case $(T_1 - T_A)/H = (110 - 55)/250 = 0.22$. The collector on the left, under these conditions would be converting 48% and the collector on the right 64% of the sun's available energy into heated water. Generally one should consider the range from 0-0.25 on the horizontal parameter.

By reading the efficiency curve of specific collectors, the designer can ascertain how a collector is likely to function under certain conditions, and choose the best equipment for the particular application.

A relatively flat curve at a high instantaneous efficiency (the verticle axis of the graphs) is desirable. Note that the horizontal and vertical scales on the right graph are not on the same scale as the one on the left so that the line appears flatter, leading the consumer to believe the collector's performance to be better than it really is. Also, the horizontal axis range is not the same on the two graphs. These differences in the presentation of the collector efficiency make it very difficult to compare collectors. Although these graphs show that the collector on the right performs somewhat better, the prices of the collectors must be compared as well. Even though thermal performance has been presented in the graphs, how much actual hot water per day can be produced per panel has not. These graphs cannot easily be used by the consumer and, thus, emphasize why thermal performance ratings are so important.

The ASHRAE 93-77 standard is for collectors only and does not reflect the total system's performance. The collector thermal performance data resulting from ASHRAE 93-77 tests are generally accepted by engineers, architects, and the trades that relate to solar devices. The thermal performance data from the ASHRAE 93-77 tests will be used in forthcoming thermal performance rating programs such as those proposed by the Solar Energy Industries Association (SEIA) and the Air Conditioning and Refrigeration Institute (ARI).

APPENDIX A.6

RESIDENTIAL HOT WATER CONSUMPTION

Design considerations for solar heating systems have forced—for the first time—a hard look at residential hot water usage. Many variables exist that affect water use in a house: age mix of residents, length of hot water piping runs, temperature setting of storage tank thermostat, etc. While it is impossible to accurately consider all of the variables, attempts have been made to take them into account in a way that closely approximates field data. Following are two widely used methods for arriving at these water use estimates.

1. HUD/PINY Formula

The HUD Hot Water Initiative $400 grant program used 20 gal of hot water per day for the first two people in a household and 15 gal per day for all others (70 gallons per day for the average family of four).

2. New England Electric Systems Formula

New England Electric Systems' study of 100 residential solar water heaters showed 16 gallons per person per day in hot water usage (64 gal for the typical family of four). On the other hand, conservation of hot water is being reflected in lower numbers of gallons used by typical families. A recent formula developed for use in the RCS Model Audit recognizes the effects of water-using appliances and the water-conserving practices recommended by the RCS auditor (e.g., setback to 120°).

3. RCS Model Audit Formula

In the RCS formula all numbers are gal/resident/day using base = 10. The average family having only a dishwasher uses 15 gal/resident/day. If the family has only a washing machine they use 20 gal/resident/day. With both appliances present they use 25 gal/resident/day.

4. Hot Water Consumption Table

A fourth way to calculate hot water demand for your own household is to refer to the following chart. Add up the total gallonage of hot water that you estimate is used daily.

HOT WATER CONSUMPTION TABLE

	Gallons/Use Hot Water Required		Gallons Used Per Day
Clothes Washing Machine	14-lb. Machine	18-lb. Machine	
a) Hot wash/hot rinse	38	48	
b) Hot wash/warm rinse	28	36	21
c) Hot wash/cold rinse	19	24	
d) Warm wash/cold rinse	10	12	
Dishwashing			
Automatic dishwasher	15		15
Sink washing	4-8		4
Personal Hygiene			
Tub bathing	20-30		15
Wet shaving/ hair washing	2-4		2
Showering			
Low-flow showerhead	1-2 gal/min		15
Regular showerhead	3-4 gal/min		25
Hand/ face washing	2		2
Food Preparation/Kitchen	3		3
Typical Household Cleaning	2-4		2

Source: Northeast Solar Energy Center, Cambridge, MA.

APPENDIX A.7

ANSWERS TO REVIEW QUESTIONS

Chapter 2

Basic Components

(1) Simple flat black sheets of copper or polypropylene have become popular for pool heating because of the favorable conditions for solar collection during the swimming (summer) months. Glazings, collector cases, collector and pipe insulation are all frequently unnecessary since the pool water circulating through the collectors is generally cooler than the outside air. For this reason, unglazed collectors offer a highly efficient and relatively inexpensive approach.

(2) Glazed flat-plate collectors are more popular for domestic hot water heating because the temperatures achieved are more consistent with the needed delivery temperatures for that application. In addition, costs of manufacturing and installation of flat-plate collectors are lower. Also, flat-plate collectors have proven more efficient than concentrating or evacuated tube collectors in conditions of diffuse light.

(3) There are literally hundreds of different methods of constructing a glazed flat plate collector. Manufacturers around the country are experimenting with many different materials as well. However, four basic components remain which define the technology at this time: the glazing, the absorber, the insulation, and the case.

(4) Black chroming and double glazing are both techniques commonly used to enhance the efficiency of flat-plate collectors by reducing losses from the absorber plate. Black chroming has become especially popular because it is increasingly inexpensive relative to the cost of double glazing. Additionally, black chrome doesn't materially increase the weight of a collector and does not suffer the 8-10% reflective loss typical of each collector glazing surface.

(5) Stagnation refers to the thermal conditions experienced by a solar collector when there is no movement of the heat transfer fluid. The stagnation temperature can be thought of as an equilibrium temperature, the high-end temperature when a collector begins to lose as much heat as it takes in.

(6) Reverse/return (or "Z") piping refers to a piping technique in which a bottom corner of a collector is fed with the cool incoming heat transfer medium while the heated transfer medium is taken from the opposite top corner of the array. This type of piping is important because it assures that all collectors have a balanced flow and, therefore, balanced heat transfer. In cases where reverse flow has not been used (and the inlet and outlet are on the same end of the collector array), it is often found that panels toward the end of the array farthest from the inlet and outlet are starved and not operating efficiently.

(7) Generally speaking, PVC piping may be used in the transport loop of very low temperature active solar systems only. PVC pipe is not made to accommodate

continuous heat higher than 100°F. Therefore, solar swimming pool heaters are the only active solar systems which commonly utilize it. Certain solar domestic hot water system manufacturers are using a CPVC and polybutylene piping. These materials should be differentiated from PVC, however, as they are capable of withstanding temperatures in the 180° range.

(8) Draindown and closed-loop systems use storage tanks pressurized to the level of the incoming street (or well) water pressure. Drainback tanks are not pressurized as they are the open nighttime receptacle for heat transfer water.

(9) Closed-loop systems are pressurized usually to a point between 10 and 40 psi. When the circulator turns on, it does not have to establish head because the antifreeze is already throughout the solar loop. In a drainback system, however, a larger pump is required. Because the heat transfer fluid (usually water) has drained back to the holding tank at the end of the previous day, the pump must have sufficient capacity not only to circulate the water but also to pump it up to the top of the collectors.

(10) All systems using water as a heat transfer medium.

(11) Most successful solar installation companies provide an annual check-up on the solar systems which they install. Whenever closed loop antifreeze systems are involved, three points become paramount. First, the pressure of the antifreeze loop must be checked to ensure that it remains at the level at which it was last set. The pressure can decrease over time, resulting in poor system performance. The most frequent cause of low pressure is leaks. All solar antifreezes have very low surface tension, allowing them to leak where water—or even air—might not. Additionally, pressure drops may be caused by the loop relief valve purging a bit of antifreeze during a stagnation condition when the circulator was not running. Second, the freeze point of the fluid should be checked in the manner specified by its manufacturer to ensure that proper strength is maintained. With propylene and ethylene glycol systems, freeze strength is easily tested with a calibrated refractometer. Third, the pH balance of the antifreeze should be tested to ensure that the fluid has not become acidic. Normally antifreeze out of the drum reads 7.5 on an acidity/alkalinity scale. If it begins to approach 6.0, it generally requires changing.

Installers should familiarize themselves with the characteristics of the specific fluid they are using.

Propylene and ethylene glycol, silicone oils, and glycerine are but a few of the common antifreezes on the market today, and they all have their own particular considerations.

(12) Water is popular because it is readily available and inexpensive. Additionally, its high specific heat offers easy, efficient heat transfer. By way of comparison, a rock storage would occupy 2-1/2 times the volume of an equivalent water storage.

(13) Rock storage requires greater volume than water storage since rock has a unit heat capacity which is two and a half times less than water. In addition to rock's lower specific heat, rock, as any solid storage material, must have internal air circulation to permit heat transfer. Therefore, the required volume needs to be increased to include a certain internal volume of air.

(14) Yes. Experienced solar designers, for example, go to great lengths to ensure that the heat exchanger size and position are such that the fluid going into the collectors is always as cool as possible.

(15) Most controller manufacturers are finding that a 20° on differential (between collectors and storage) and a 3° off differential work well in solar water heating systems.

Solar Domestic Hot Water Systems

(1) Tilt angles—± 10° from local latitude.
Azimuth angles—± 15° from true south.

(2) A Btu is the amount of energy required to raise one pound of water one degree Fahrenheit.

(3) 120° - 140° temperatures are typical.

(4) There can be an enormous difference in the amount of hot water used daily person to person, family to family. When a solar installer is sizing a solar water heater, it is critical to go to some lengths to find out what the specific usage pattern is and whether conservation measures such as low-flow showerheads, etc. are in place. When such information is simply not available, however, many designers are comfortable with a figure of 20 gal/person/day.

(5) Solar systems are generally not sized to provide 100% contribution because of the seasonal nature of the climate in this country. If a system were made large enough to provide 100% of energy needs from solar during the less favorable winter months, it would often mean that during the summer, the system would be providing far more energy than could be used. This overproduction would, of course, dramatically decrease the cost efficiency of the installation. As a rule of thumb, many designers aim for a 50%-70% solar fraction, feeling that this range offers the best value in terms of delivered Btu per dollar invested.

(6) If an integral backup element is used in a solar storage tank, it is important that the element and the water heated by it be separated as much as possible from the solar heated water and the solar loop inlet and return. If this were not done, the entire tank might be heated electrically. The result would be a much decreased solar contribution.

In light of these considerations, most manufacturers of stone-lined tanks for closed loop systems, for example, place the solar heat exchanger in the very bottom of the tank next to the incoming cold potable water. The backup electric element, on the other hand, is placed far up in the tank. When solar collection occurs, the bottom of the tank will be heated only by solar. As this heating takes place, the hottest solar-derived water will move by natural thermosyphoning toward the top of the tank. In this way the electric backup will often work only against the hottest possible solar-heated water, thereby increasing the efficiency of the system.

(7) By-pass interfaces are popular because they allow homeowners to draw directly from their primary solar storage during periods of high insolation. In this mode, the solar-heated water does not have to pass through a second tank on the way to the faucet. Additionally, the stand-by loss of the second tank is avoided.

One final factor comes into play. If in the summer months a family is not home during the day, it is possible for the solar storage tank to reach 160° or more. In the meantime, however, the backup in the second tank may have to come on just to keep that tank hot. Since there is no demand, no hot water would be moving from the solar to the backup tank. The by-pass technique would in this instance allow the homeowner to save by shutting off not only the second tank (preventing line and tank losses) but the backup energy source as well.

(8) a. Install low-flow showerheads and faucet aerators.
   b. Insulate all hot water delivery lines to faucets and keep them as short as possible.
   c. Maintain the lowest possible settings on the backup energy source and tempering valve.
   d. Turn off the backup energy source whenever possible.

(9) The following general formula applies:

$\underline{\text{gal/day}} \times \underline{\text{lb/gal}} \times \underline{\text{temp. rise}} \times \underline{\text{days/year}} = \underline{\text{Btu/year}}$ or,

$75 \times 8.33 \times 80 \times 365 = 18{,}242{,}700$ Btu/year

(10) The only system which requires a solar loop pressure relief valve is a system which is independent and runs under pressure—the closed loop.

Active Solar Space Heating System

(1) Tilt angles—latitude to latitude-plus-15°.
Azimuth angles— ± 15° from true south.

(2) The relatively large number of collectors required for adequate active solar space heating often exceeds the amount of space available on the roof of an existing home and the ability of the roof structure to support them. Additionally, to maintain a proper ratio of collection area to storage volume, a large area is generally needed for storage.

Also, unlike water heaters, a solar space heating system cannot always be easily tied into the home's heat distribution system. Renovation or replacement of ducts or baseboard are frequently required. Finally, economics of the space heating retrofit are often difficult to justify because the success of the solar system relates very much to the thermal quality of the building it heats. Only after conservation improvements in insulations, windows, doors, etc. are completed should solar space heating be considered.

(3) F-Chart is a computer design tool for calculating the amount of energy which an active solar system will provide toward a hot water and/or space heating load.

(4) a. air distribution
  b. forced hot water distribution
  c. parallel forced hot water distribution

(5) A water-to-air heat exchanger is a device used to dissipate heat out of a water source into air. An automobile radiator is a prime example. Water-to-air heat exchangers are popular in solar systems using water storage and air distribution. The unit is typically placed in a return air trunk in line before the home's furnace so that the furnace blower will move cool air across the warm heat exchanger.

(6) Air distribution systems interface better with solar than hydronic systems because air ducts are capable of delivering heat at lower temperatures which are more typical of solar storage.

(7) a. Consideration must be given to the amount of baseboard in place. Baseboard is often minimally sized, thereby relying on 180° boiler delivery temperatures to produce proper convective action.

  b. By-pass valving must be used so that either the solar tank or the boiler is supplying the baseboard with hot water, but not both.

(8) Fan coil units are independent water-to-air heat exchangers often used with solar systems to provide supplemental heat to specific living areas of a home. They are popular because of their ability to operate at moderate temperatures, their effective heat exchange characteristics, and their compactness and relative ease of installation.

(9) A two-stage thermostat is useful in controlling stepped heating systems. An example would be the dual mode operation of a water storage/air distribution solar system. The first stage would control the solar heat alone. When the solar heat exchange coil cannot provide sufficiently high temperatures, the second stage is activated and the furnace provides backup heat.

(10) First, the provision of water heating will allow the space heating system to contribute Btus on a year round basis, summer and winter, which is often very helpful economically. Second, by providing hot water in the summer, a method is provided to draw off heat which can otherwise be excessive both in the collection and storage systems.

Solar Swimming Pool Heating Systems

(1) Tilt angles--latitude to latitude-minus-15°.
Azimuth angles— ± 45° from true south.

(2) Pool heaters are not complex because they normally do not have to provide heat during cold weather and because they are usually not subject to nighttime freezing.

(3) When unglazed pool collectors are used, certain rule-of-thumb sizing methods can often be used. One major manufacturer recommends that a minimum of 50% of the pool surface area be sized in collector area for south-facing installations. The ratio would increase to 75% of the pool area for east- or west-facing systems.

(4) An important consideration in planning a solar/pool interconnection is to ensure that the existing pool pump is adequately sized to maintain a sufficiently high flow rate through the collectors. As a rough guide, 1/2-hp circulation pumps will generally not be adequate but 3/4-hp pumps are usually sufficient for systems on 15,000-gal pools. Moreover, it is important to consider the age of the pump as old and worn units sometimes have less capacity than their stated rating.

Inspector's Checklists and Discussion

(1) An Abney Level is a siting tool with a degree indicator. It is useful in determining roof pitches and solar angles.

(2) March 21, the first day of spring, is the vernal equinox. In any given location, at solar noon the sun will be perfectly perpendicular to true south-facing solar collectors placed at a tilt angle equal to local latitude.

(3) Due to the earth's magnetic field, it is necessary to adjust the compass reading by a few degrees east or west to obtain true north (different from magnetic north) for your area. This adjustment is the isogonic correction.

(4) Without the 1-1/2 in. minimum space provided by collector standoffs, fungus, mildew and mold can grow beneath the panels because of moisture buildup and entrapment. Over the years, serious roof deterioration can result.

Additionally, without drainage space beneath collectors, ice dams can form at the top of the array causing leaks.

(5) a. Direct lagging into rafters
b. Blocking technique
c. Spanner mounting

(6) 60 - 150 lb.

(7) ASHRAE 93-77 is a thermal testing technique for solar collectors developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers. The purpose of the test is to provide a consistent method for comparing the efficiencies of different collectors under different operating conditions. The test result is a curve on a graph describing efficiency conditions relative to usable output energy and solar energy input.

(8) A weep hole is a small hole (often 1/4 in.) placed in the bottom edge strip of a glazed flat-plate collector to allow condensation to drain out of the casing.

(9) Solar piping under 1 in.-- R-4.
Solar piping 1 in. or more— R-6.
Storage tanks— R-11.

(10) If a check valve is not installed in the loop, reverse thermosyphoning can occur at night, dissipating large amounts of heat collected during the day.

(11) HUD IMPS calls for tempering valves or similar devices to limit domestic hot water delivery temperatures to 140° or less because solar water heaters in times of low demand and high insolation are easily capable of 180° storage temperatures. Unmixed delivery of water at these temperatures could scald a user. Additionally, by tempering the water with a mixing valve, heated water is conserved, offering greater solar cost efficiency.

(12) Certain codes require backflow preventers to avoid any possiblility of solar heat transfer fluids contaminating the potable water supply, should those fluids leak from the solar loop.

(13) Vertical piping—10 ft maximum.
Horizontal piping—6-ft intervals for pipe less than 1-1/2 in. diameter and 10-ft intervals for pipe over 2 in. in diameter.

(14) A fill/drain assembly is a device typically found in closed-loop solar water heaters which consists of two boiler drains and a check valve or gate valve between them. Installed at the low point of the solar loop, it allows the installer to fill a system with the appropriate heat transfer fluid, to achieve the proper fill pressure, and to purge all the entrapped air from the system.

(15) Relief valves must always be vent-piped so that if they relieve fluid, the occupants of the building are in no danger of potentially scalding fluids. The specific venting requirements are usually covered under local plumbing codes.

(16) All sensors must be placed and wired strictly according to the instructions from the manufacturer. They must make proper thermal contact and in most cases be protected from ambient weather conditions. No sensor wiring may be run near hard heavy wiring since by magnetic induction the sensor wire may produce faulty resistance readings.

All controllers must be handled carefully and the high voltage for the pump must be kept clear of the low voltage wiring to the sensors. The pump wiring should precede the line voltage wiring to the controller, as an open load can damage many controllers. In all cases, manufacturers' instructions are to be followed strictly.

Circulators and backup elements are considered permanent electrical fixtures and all wiring must carefully follow the procedures determined by local code.

Chapter 4

(1) a. Collectors should, where possible, be positioned so that the array can be easily expanded in the future. The need for expansion may arise with an increased water heating demand or a decision to use solar heat for an additional application.

b. Collectors should be placed where they are easy to service. Solar systems are heating machines which do need occasional service. Arrays which are not accessible add greatly to the cost of repair or replacement.

c. Collectors and their piping should be positioned so as to be completely drainable.

d. Collectors should, as much as possible, be kept away from chimneys so that chimney emissions will not collect on glazing and reduce solar input.

e. Particularly when racked away from the roof slope, collectors should be placed where wind uplift forces will be minimized.

f. Where possible, collectors should not be placed over entrances in order to avoid injuries from snow slides.

(2) The concern in working with asphalt shingles is that major damage to a roof can occur either during very cold weather when shingles become brittle and fragile or in very hot weather when the shingles become overly pliable and compressible. If work must be done during either of these extreme weather conditions, it is highly advisable to use a roof staging of some type.

Many other types of roofing materials now used, such as clay tiles, wood shake shingles, or slate, must be treated differently. In these cases, the roofing material must be either cut or chipped away so that the bearing load of the collector array is fed directly to the sheathing. The roof penetration must be very carefully sealed. Because these materials are so fragile, great care must be taken when working with them.

(3) Great care must be taken when insulating outdoor solar piping. Any small crack or opening in a seam may expand over time through exposure to the elements and allow water to travel into the building along the solar piping. The most important material consideration is that all insulation be covered with a coating which is resistant to ultraviolet light. Urethane foams, for example, are available with u-v inhibited PVC and Do-All jackets.

(4) a. Whenever possible, storage vessels must be placed in a heated area.

b. Storage vessels should be placed as close as possible to auxiliary heating equipment to reduce line losses.

c. Storage vessels must have adequate space around them so as to be accessible for service.

d. Consideration must be given to the weight of the storage tank in relation to the load bearing capacity of the floor. For example, a typical stonelined 80-gal tank for a 3-panel water heater weighs approximately 450 lb dry and nearly 1200 lb when operational.

e. Attention must be given to door widths. Many solar storage tanks are 26-in. wide and may be difficult to fit through a narrow door or around a tight staircase.

(5) Certain types of contemporary homes use rigid board insulation between sheathing and shingles. This insulation technique deserves special attention because the weight of collectors can compress the board over time, allowing the collector attachment points to weaken. One preferred approach is to locate precisely where the collector footings will be and to cut away the shingles and insulation down to the sheathing. A wooden spacer of the same thickness as the insulation is then installed and the shingles covering the spacer replaced.

(6) Attempting to run piping through closed walls often results in encountering invisible barriers such as wiring, fire stops, structural members, etc. Also, in most cases, it is impossible to insulate loop piping properly when feeding it through a narrow wall cavity.

(7) Most installers first look for closets that line up properly. Well-insulated pipes can be conveniently and unobtrusively run in back corners of closets.

Chapter 5

Domestic Water Heating Systems

1. Automatic, Storage
2. Gas Valve
3. Anode
4. Improper Gas Vent Operation
5. Gravity Vents
6. Flue, Exchanger
7. Water
8. False
9. Atomizing
10. Electric, Resistance
11. Drained, Scale
12. Opening the valve at the bottom of the tank.
13. a. burners
    b. flue
    c. anode
    d. vent, draft
14. Corrosion
15. Dew point

Residential Heating Systems

1. To provide human comfort when outside weather conditions are too cool for human comfort.
2. C
3. B
4. D
5. Heats, electrical, open
6. A
7. B
8. To safely exhaust the products of combustion from the appliance to the ouside atmosphere.
9. B
10. A
11. Adjusted

12. B
13. B
14. The thermostat
15. A
16. Hot water and steam
17. B) False
18. C
19. B) False
20. D
21. Heat Exchanger
22. C
23. C
24. C

Chapter 7

Wind Energy Systems

1. 1 - Atmospheric
2. 1 - Atmospheric, 2 - Wind Tunnel, and 3 - Towing
3. 2 - 2.4 kW
4. 3 - determine the wind speed at the rotor height
5. 5 - manufacturer
6. 4 - manufacturers
7. 2 - the manufacturers or representative
8. 2 - the manufacturer
9. 2 - user side
10. 1 - backable disconnect switch
11. 2 - power delivered by the SWECS minus power consumed by the control subsystems and power conditioning equipment
12. 3 - NEC as augmented by local codes
13. 1 - yes
14. 1 - yes
15. 1 - yes
16. 2 - no
17. 2 - no
18. 2 - no
19. 2 - no
20. 2 - wind speed or wind run

APPENDIX A.8

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